

Supplementary Materials

Supplementary Table 1. Comparison of existing AF prediction models on UKBB Development Dataset

Method	AUROC	Accuracy	Sensitivity	Specificity	PPV
CHARGE-AF Clinical Risk Factors	0.7619	0.7657	<u>0.7091</u>	0.8146	0.7678
CHA ₂ DS ₂ -VASc Score	0.7200	0.7241	0.6649	0.7752	0.7188
C ₂ HEST Score	0.7399	0.7396	0.7453	0.7346	0.7083
DenseNet121	0.7012	0.6557	0.6555	0.6559	0.6160
EfficientNet_B3	0.8286	0.7799	0.6179	0.9200	0.7921
ResNet50	0.8265	0.7694	0.6340	0.8864	0.8177
RETFound	0.5053	0.5369	0.0254	0.9791	0.4705
RetiAF Score (Ours)	<u>0.8610</u>	<u>0.8011</u>	0.6354	<u>0.9484</u>	<u>0.9162</u>
Hybrid_RetiAF Score (Ours)	0.8924	0.8191	0.6711	0.9507	0.9236

Supplementary Table 2. Comparison of Different AF Prediction Models on Validation Datasets

Dataset	Method	AUROC	Accuracy	Sensitivity	Specificity	PPV
UKBB Testing Dataset	RETFound	0.5206	0.7352	0.1535	0.8250	0.1256
	CHARGE-AF Clinical Risk Factors	0.7553	0.7130	<u>0.7884</u>	0.7112	<u>0.2982</u>
	CHA ₂ DS ₂ -VASc Score	0.7031	0.6895	0.7215	0.6846	0.2610
	C ₂ HEST Score	0.7246	0.6710	0.7978	0.6514	0.2611
	DenseNet121	0.6747	0.6465	0.5852	0.6560	0.2080
	EfficientNet_B3	0.7806	0.7061	0.6696	0.7117	0.2640
	ResNet50	0.7665	0.6672	0.7022	0.6617	0.2427
	RetiAF Score (Ours)	<u>0.8019</u>	<u>0.7211</u>	0.6846	<u>0.7268</u>	0.2790
	Hybrid_RetiAF Score (Ours)	0.8381	0.7619	0.7396	0.7653	0.3273
Shanghai Local Dataset	RETFound	0.6889	0.8718	0.1893	0.9157	0.1117
	CHARGE-AF Clinical Risk Factors	0.5151	0.1783	0.8335	0.1362	0.0587
	CHA ₂ DS ₂ -VASc Score	0.5653	0.0593	0.8614	0.0078	0.0539
	C ₂ HEST Score	0.5754	0.0605	0.8386	0.0105	0.0530
	DenseNet121	0.6022	0.6020	0.4599	0.6111	0.0855
	EfficientNet_B3	0.7647	0.6592	<u>0.8792</u>	0.6451	0.1097
	ResNet50	0.7435	0.6036	0.8157	0.5899	0.1211
	RetiAF Score (Ours)	<u>0.7803</u>	<u>0.7538</u>	0.8018	<u>0.7508</u>	<u>0.1253</u>
	Hybrid_RetiAF Score (Ours)	0.8694	0.7158	0.8869	0.7058	0.3263

Supplementary Table 3. Subgroup Analysis of Model Performance in the UKBB and Shanghai Cohorts

Dataset	Cohorts	Method	AUROC	Accuracy	Sensitivity	Specificity
UKBB Internal Testing	Female	RetiAF	0.7989	0.7388	0.6553	0.7474
		Hybrid_RetiAF	0.8438	0.7513	0.7595	0.7505
	Age ≥ 65	RetiAF	0.7531	0.5968	0.7476	0.5409
		Hybrid_RetiAF	0.8051	0.6053	0.8511	0.5142
	C ₂ HES _T ≥ 3	RetiAF	0.9619	0.9849	0.8451	0.9886
		Hybrid_RetiAF	0.9936	0.9200	0.9956	0.9181
Shanghai Local Dataset	Female	RetiAF	0.7948	0.7842	0.8178	0.7027
		Hybrid_RetiAF	0.7985	0.7711	0.8364	0.6126
	Age ≥ 65	RetiAF	0.5977	0.5839	0.8390	0.5298
		Hybrid_RetiAF	0.6987	0.4938	0.9477	0.3977
	C ₂ HES _T ≥ 3	RetiAF	0.7455	0.6647	0.7094	0.5752
		Hybrid_RetiAF	0.7469	0.6909	0.9026	0.2669

Supplementary Table 4. CIHD prediction performance on the UKBB Dataset

Method	AUROC	Accuracy	Sensitivity	Specificity
C ₂ HES _T Score	0.6622 $\pm$ 0.0103	0.6193 $\pm$ 0.0055	0.7312 $\pm$ 0.0250	0.5931 $\pm$ 0.0088
RetiAF Score (Ours)	0.6964 $\pm$ 0.0152	0.6597 $\pm$ 0.0096	0.7557 $\pm$ 0.0264	0.6371 $\pm$ 0.0080
Hybrid_RetiAF Score (Ours)	0.7061$\pm$0.0144	0.6723$\pm$0.0074	0.7607$\pm$0.0322	0.6515$\pm$0.0098

Supplementary Table 5. CIHD prediction performance on the low risk group people from UKBB

Dataset

Method	AUROC	Accuracy	Sensitivity	Specificity
C ₂ HES _T Score	0.5401±0.0253	0.3973±0.0450	0.7350±0.0503	0.3451±0.0057
RetiAF Score	0.6579±0.0130	0.6474±0.0262	0.6706±0.0475	0.6453±0.0322
Hybrid_RetiAF Score	0.6701±0.0255	0.6848±0.0249	0.6525±0.0567	0.6877±0.0290

Supplementary Table 6. ICD-10 definitions for comorbidities

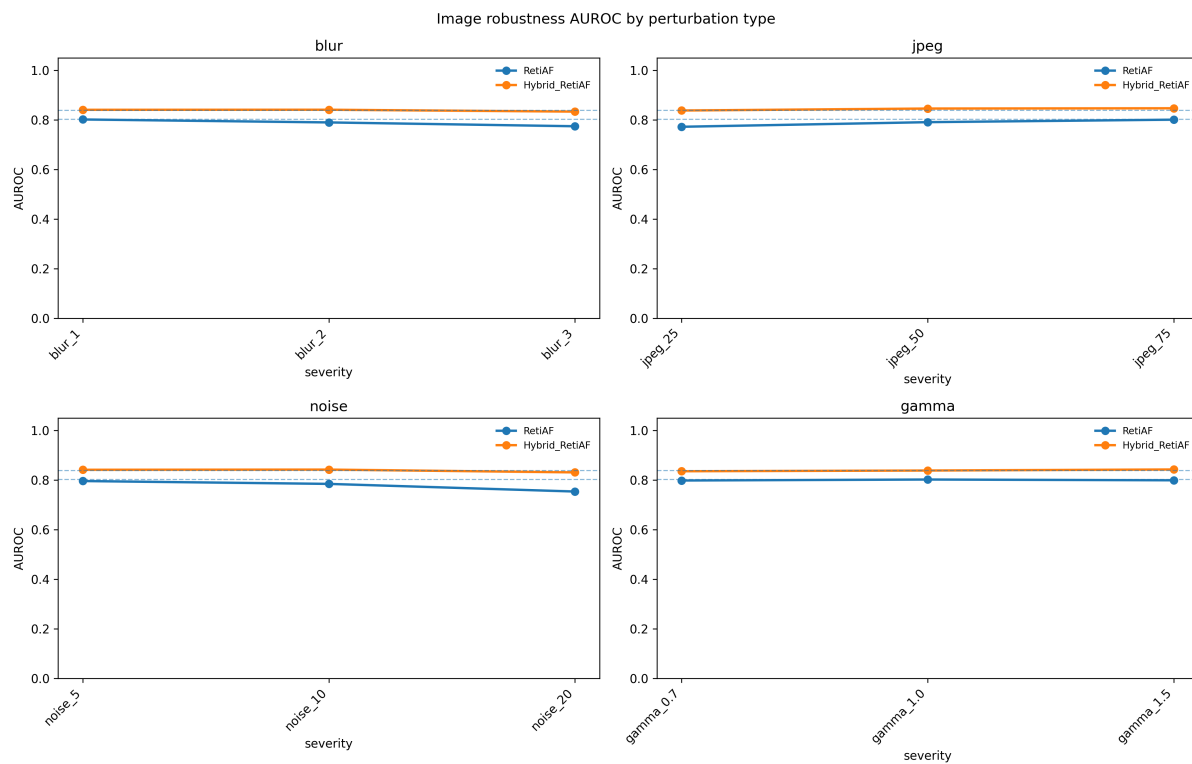
Description	ICD-10 codes
Atrial Fibrillation, Atrial Flutter	I48
Heart failure	I25.5, I50, I11.0, I13.2, I13.9, I42.0, I42.5-9, I43
Hypertension	I10, I11, I12, I13, I15
Prior CVA/TIA/TE	I63, I64.9, G45, I74, I26
Prior myocardial infarction	I21, I23
Peripheral arterial disease	I70, I71, I73.9
Diabetes	E10, E11
Smoker	F17.1, F17.29, F17.21, F17.20, Z86.43, Z87.891, Z71.6, Z72.0

Supplementary Table 7. Definition of lifestyle factors in the UK Biobank.

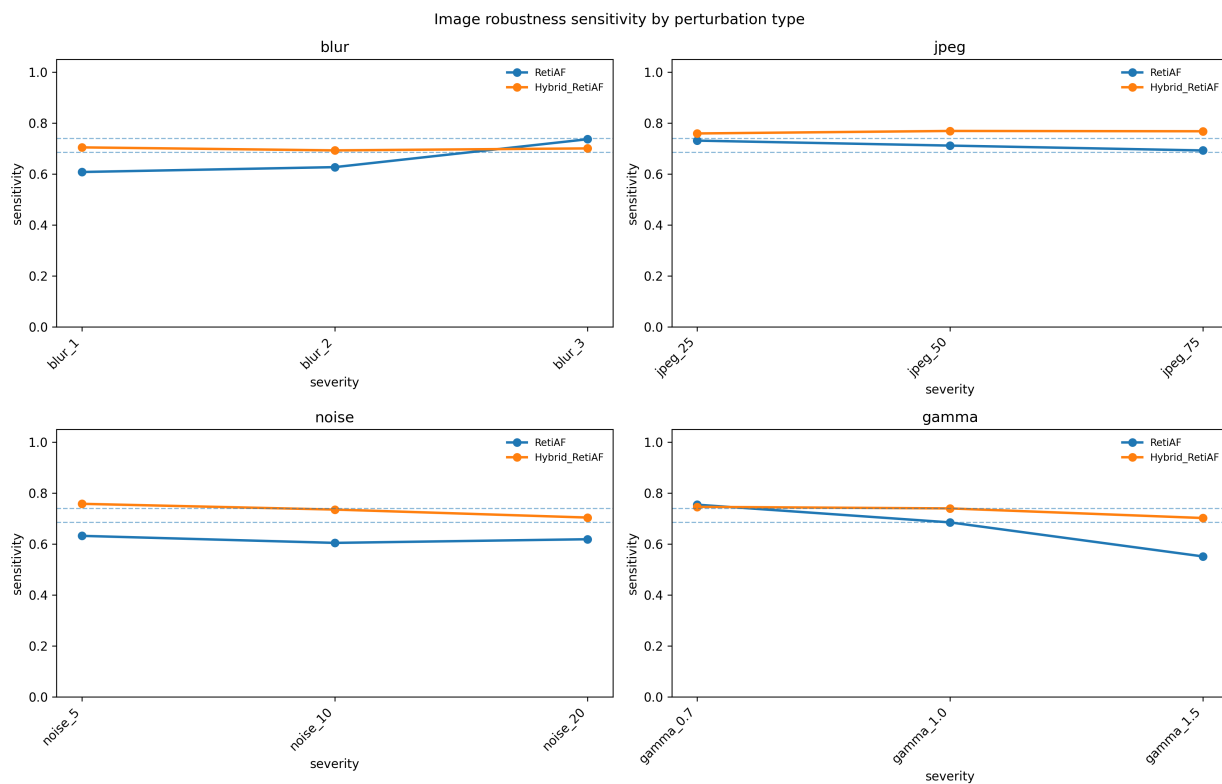
Factors	Unhealthy level	Healthy level
Alcohol consumption	Heavy alcohol consumption: women: ≥ 3 drinks /day men: ≥ 4 drinks /day one drink is measured as 8 g ethanol in the U.K.	Never or moderate consumption: women: 0 and < 3 drinks /day men: 0 and < 4 drinks /day or never deinked one drink is measured as 8 g ethanol in the U.K.
Smoking status	Smoking	Non-smoking
Physical activity	0-149 min/week of moderate activity OR 0-74 min/week of vigorous activity OR 0-149 min/week of moderate and vigorous activity	≥ 150 min/week of moderate activity OR ≥ 75 min/week of vigorous activity OR ≥ 150 min/week of moderate and vigorous activity
Diet	Intake of 0-3 healthy dietary components: 1. Fruits: ≥ 3 servings/day 2. Vegetables: ≥ 3 servings/day 3. Fish: ≥ 2 servings/week 4. Processed meats: ≤ 1 serving/week 5. Unprocessed red meats: ≤ 1.5 servings/week 6. Whole grains: ≥ 3 servings/day 7. Refined grains: ≤ 1.5 servings/day	Intake of ≥ 4 dietary healthy dietary components: 1. Fruits: ≥ 3 servings/day 2. Vegetables: ≥ 3 servings/day 3. Fish: ≥ 2 servings/week 4. Processed meats: ≤ 1 serving/week 5. Unprocessed red meats: ≤ 1.5 servings/week 6. Whole grains: ≥ 3 servings/day 7. Refined grains: ≤ 1.5 servings/day

Supplementary Table 8. AUROC change over different noise setting

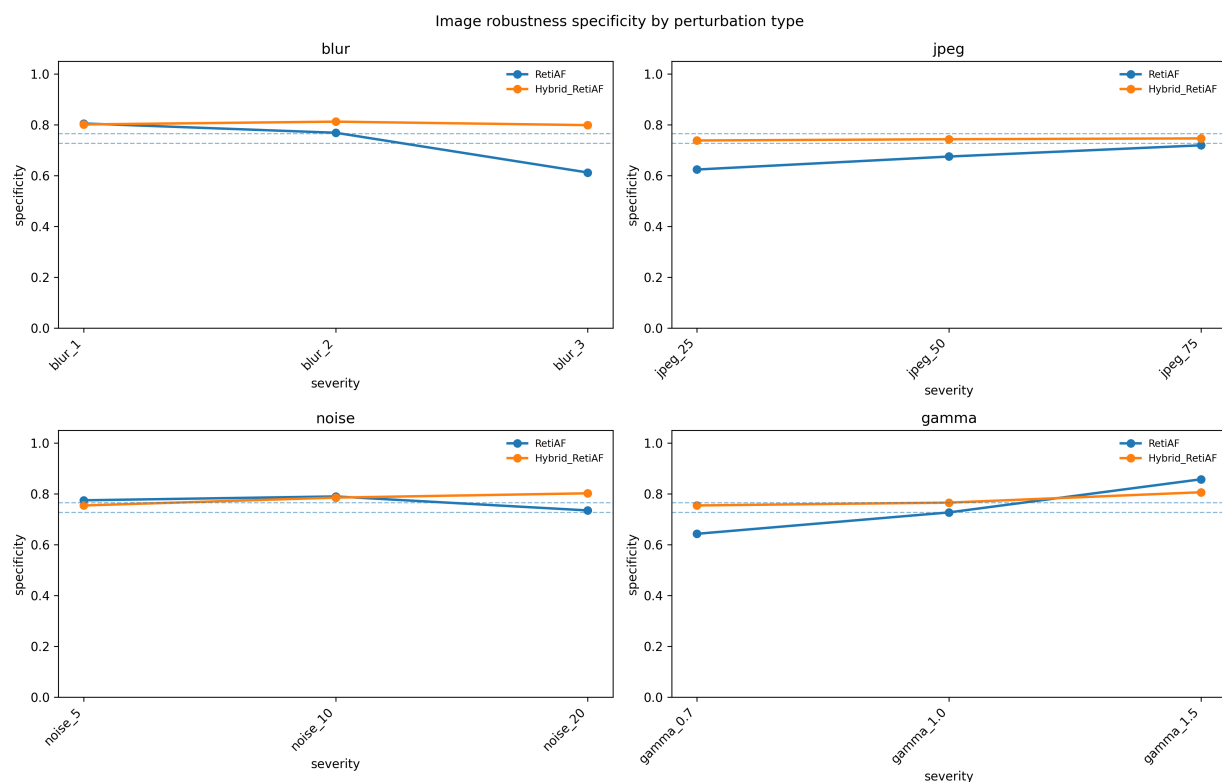
Method	AUROC	Worst perturbed setting	Worst AUROC	Max AUROC drop
RetiAF Score	0.8019	noise_20	0.7535	0.0484 (6.04%)
Hybrid_RetiAF Score	0.8381	noise_20	0.8307	0.0074 (0.88%)



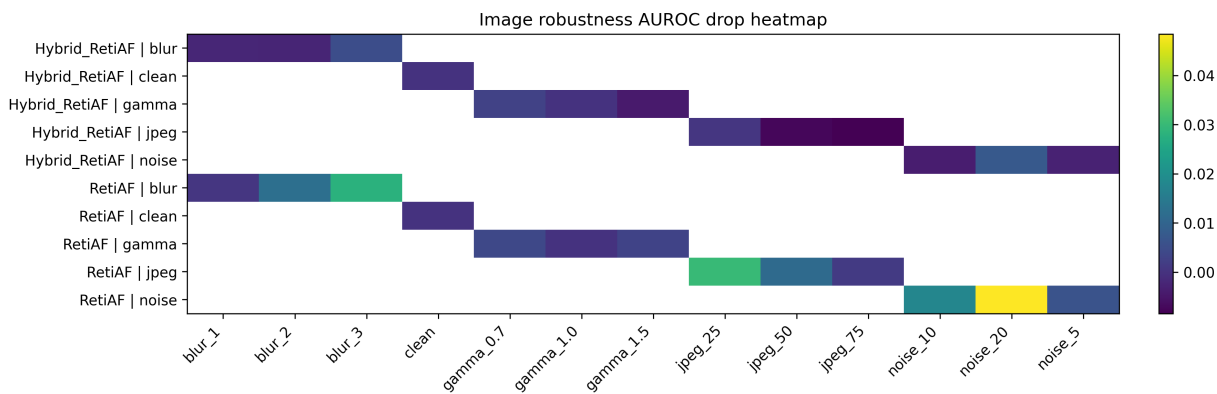
Supplementary Figure 1. Image robustness AUROC by perturbation type and severity.



Supplementary Figure 2. Image robustness sensitivity by perturbation type and severity.



Supplementary Figure 3. Image robustness specificity by perturbation type and severity.



Supplementary Figure 4. AUROC-drop heatmap across model and perturbation settings.

Supplementary Table 9. Race-stratified subgroup analysis of RetiAF and Hybrid_RetiAF performance in the UKBB internal testing cohort

Race group	n	Method	AUROC	Accuracy	Sensitivity	Specificity
White	61,526	RetiAF	0.8059	0.7254	0.6901	0.7313
		Hybrid_RetiAF	0.8440	0.7712	0.7391	0.7765
Black or Black British	2,661	RetiAF	0.7164	0.6704	0.5446	0.6754
		Hybrid_RetiAF	0.7702	0.6569	0.8020	0.6512
Asian or Asian British	2,491	RetiAF	0.7333	0.6873	0.5985	0.6924
		Hybrid_RetiAF	0.7911	0.6953	0.7591	0.6916
Mixed	633	RetiAF	0.7713	0.7220	0.5938	0.7288
		Hybrid_RetiAF	0.7815	0.7204	0.6875	0.7221
Chinese	337	RetiAF	0.7505	0.6736	0.4500	0.6877
		Hybrid_RetiAF	0.7640	0.7151	0.5500	0.7256
Others	1,188	RetiAF	0.7490	0.7155	0.5758	0.7282
		Hybrid_RetiAF	0.7924	0.7062	0.6970	0.7071

Supplementary Table 10. Metabolomics Sensitivity Analysis on the Internal UKBB Testing Dataset

Method	AUROC	Accuracy	Sensitivity	Specificity	PPV
NMR Features Only	0.7442	0.8462	0.4179	0.9123	0.4238
RetiAF Score	0.8019	0.7211	0.6846	0.7268	0.2790
RetiAF Score + NMR Features	0.8096	0.7444	0.6820	0.7540	0.2998
Hybrid_RetiAF Score	0.8381	0.7619	0.7396	0.7653	0.3273
Hybrid_RetiAF Score + NMR Features	0.8418	0.7649	0.7350	0.7695	0.3299