

Supplementary Material (A), 'Tables in Text'

Manuscript – “Investigating for bias in healthcare algorithms: A sex stratified analysis of supervised machine learning models in liver disease prediction”

Section 2.1 Supplementary: Data Exploration and Initial Analysis

Supplementary Table 1.0 gives the variables included in our dataset and their initial datatypes (gender is later converted to binary numerical form).

Supplementary Table 1.0 Features of the Indian Liver Patient Dataset

Column	Datatype	Description
Age	Int64	Age of patient
Gender	Object	Sex of patient
Total Bilirubin (TB)	Float64	Bilirubin is synthesised by the liver and acts as a marker of liver function.
Direct Bilirubin (DB)	Float64	Bilirubin is synthesised by the liver and acts as a marker of function.
ALP (Alkphos Alkaline Phosphatase)	Int64	An enzyme produced by the liver acting as a marker of function.
SGPT Alamine Aminotransferase	Int64	An enzyme produced by the liver acting as a marker of function.
SGOT Aspartate Aminotransferase	Int64	An enzyme produced by the liver acting as a marker of function.
Total Proteins (TP)	Float64	The liver synthesis proteins, this count reduces with disease.
Albumin (ALB)	Float64	The liver synthesis proteins, this count reduces with disease.
Selector Field	Float64	Column that indicates whether a patient has liver disease or not, this has been previously labelled by experts.

2.2 Supplementary; Feature Exploration

Supplementary Table 2.0 presents sex-stratified feature importance ranked by Pearson's correlation coefficient.

Supplementary Table 2.0 Feature importance ranked by Pearson Correlation Coefficient

Feature Rankings: Pearson Correlation with Target Variable (Diagnosis of Liver Disease)					
All Patients		Female Patients		Male Patients	
Feature	Pearson Correlation Coefficient	Feature	Pearson Correlation Coefficient	Feature	Pearson Correlation Coefficient
1. Direct Bilirubin (DB)	0.25	1. Alkaline Phosphotase (ALP)	0.24	1. Direct Bilirubin (DB)	0.25
2. Total Bilirubin (TB)	0.22	2. Direct Bilirubin (DB)	0.22	2. Total Bilirubin (TB)	0.22
3. Alkaline Phosphotase (ALP)	0.18	3. Total Bilirubin (TB)	0.22	3. Albumin (ALB)	0.19
4. SGPT Alamine Aminotransferase	0.16	4. SGPT Aspartate Aminotransferase (AST)	0.22	4. Age	0.17
5. A/G Ratio	0.16	5. SGPT Alamine Aminotransferase	0.19	5. A/G Ratio	0.17
6. Albumin (ALB)	0.16	6. A/G Ratio	0.15	6. Alkaline Phosphotase (ALP)	0.16
7. SGPT Aspartate Aminotransferase (AST)	0.15	7. Albumin (ALB)	0.07	7. SGPT Alamine Aminotransferase	0.16
8. Age	0.14	8. Total Proteins (TP)	0.05	8. SGPT Aspartate Aminotransferase (AST)	0.14
9. Gender	0.08	9. Age	0.02	9. Total Proteins (TP)	0.06
10. Total Proteins (TP)	0.04	10. Gender	N/A	Gender	N/A
Sum of correlation			1.38		1.52
Q1			0.07		0.16
Q3			0.22		0.19
Mean IQR			0.145		0.175

Supplementary Table 3.0: Summary Experiment 1 (Unbalanced Training Data, No Feature Selection)

	Random Forest Classifier			Logistic Regression Classifier			Support Vector Machine			Gaussian Naive Bayes		
	Mean	Standard Deviation	T Test Significance (Female to Male)	Mean	Standard Deviation	T Test Significance (Female to Male)	Mean	Standard Deviation	T Test Significance (Female to Male)	Mean	Standard Deviation	T Test Significance (Female to Male)
All Accuracy	78.17	2.36		71.31	2.37		79.40	2.50		71.53	2.61	
All FScore	76.57	2.86		68.18	2.88		79.29	2.91		64.18	3.65	
All ROC_AUC	78.25	2.30		71.42	2.28		79.44	2.47		71.49%	2.33%	
All Precision	82.65	3.69		77.04	3.98		80.46	3.95		85.98%	4.12%	
All Recall	71.58	4.69		61.37	4.19		78.59	6.01		51.37%	4.36%	
Females Accuracy	76.06	4.40	0.00	73.33	3.95	0.01	81.55	4.80	0.02	73.45	4.57	0.02
Females FScore	64.09	7.50	0.00	55.24	7.28	0.00	76.03	7.18	0.00	51.11	7.93	0.00
Females ROC_AUC	72.55	4.76	0.00	68.04	3.91	0.00	80.91	5.46	0.08	66.66%	3.91%	0.00
Females Precision	78.52	10.63	0.00	81.31	11.31	0.30	78.01	9.48	0.00	88.66%	8.11%	0.05
Females Recall	55.27	9.49	0.00	42.70	7.85	0.00	76.68	13.47	0.04	36.37%	7.58%	0.00
Females FNR	44.73	9.49	0.00	57.30	7.85	0.00	23.32	13.47	0.08	63.63	7.58	0.00
Females TNR	89.84	5.69	0.00	93.38	4.64	0.00	85.13	7.89	0.00	96.95	2.26	0.00
Females FPR	10.16	5.69	0.00	6.62	4.64	0.00	14.87	7.89	0.00	3.05	2.26	0.00
Females TPR	55.27	9.49	0.00	42.70	7.85	0.00	76.68	13.47	0.04	36.37	7.58	0.00
Males Accuracy	79.02	2.81		70.49	2.74		78.57	2.85		70.74	3.08	
Males FScore	79.72	2.98		71.11	3.14		80.17	2.94		67.30	3.90	
Males ROC_AUC	79.36	2.71		70.97	2.71		78.50	2.92		72.20%	2.79%	
Males Precision	83.76	3.75		76.44	4.52		81.42	4.09		85.53%	4.25%	
Males Recall	76.29	4.82		66.76	4.80		79.26	5.04		55.68%	4.83%	
Males FNR	23.71	4.82		33.24	4.80		20.74	5.04		44.32	4.83	
Males TNR	82.42	3.99		75.18	4.77		77.73	5.85		88.71	3.66	
Males FPR	17.58	3.99		24.82	4.77		22.27	5.85		11.29	3.66	
Males TPR	76.29	4.82		66.76	4.80		79.26	5.04		55.68	4.83	

Supplementary Table 4.0 Summary Experiment 2 (Balanced Training Data, No Feature Selection)

	Random Forest Classifier			Logistic Regression Classifier			Support Vector Machine			Gaussian Naive Bayes		
	Mean	Standard Deviation	T Test Significance (Female to Male)	Mean	Standard Deviation	T Test Significance (Female to Male)	Mean	Standard Deviation	T Test Significance (Female to Male)	Mean	Standard Deviation	T Test Significance (Female to Male)
All Accuracy	81.66	2.33		74.53	1.96		83.30	1.75		74.75	1.97	
All FScore	76.52	3.09		65.63	2.88		80.07	2.25		62.80	3.26	
All ROC_AUC	80.22	2.41		72.40	1.97		82.70	1.85		71.67	1.97	
All Precision	84.80	3.38		78.52	4.30		82.71	3.84		85.28	3.80	
All Recall	69.87	4.42		56.57	3.85		77.91	4.71		49.83	3.77	
Females Accuracy	84.75	3.03	0.00	77.71	2.42	0.00	89.03	2.23	0.00	78.47	2.35	0.00
Females FScore	71.41	5.74	0.00	51.69	5.87	0.00	82.18	3.72	0.00	51.55	5.38	0.00
Females ROC_AUC	78.47	3.76	0.13	67.10	2.86	0.00	86.87	3.01	0.00	67.12	2.59	0.00
Females Precision	85.44	6.07	0.88	82.22	8.04	0.00	84.22	5.64	0.14	85.13	7.00	0.37
Females Recall	61.70	7.03	0.00	38.12	6.09	0.00	80.88	6.90	0.00	37.19	5.02	0.00
Females FNR	38.30	7.03	0.00	61.88	6.09	0.00	19.12	6.90	0.00	62.81	5.02	0.00
Females TNR	95.24	2.03	0.00	96.09	2.04	0.00	92.86	3.00	0.00	97.05	1.48	0.00
Females FPR	4.76	2.03	0.00	3.91	2.04	0.00	7.14	3.00	0.00	2.95	1.48	0.00
Females TPR	61.70	7.03	0.00	38.12	6.09	0.00	80.88	6.90	0.00	37.19	5.02	0.00
Males Accuracy	78.58	3.05		71.35	3.22		77.56	2.93		71.04	3.22	
Males FScore	79.10	3.21		71.86	3.41		78.78	3.10		68.20	3.96	
Males ROC_AUC	79.07	2.93		71.89	3.07		77.80	2.95		72.57	2.82	
Males Precision	84.49	3.92		77.47	4.44		81.90	4.62		85.37	4.05	
Males Recall	74.59	4.93		67.34	5.33		76.24	5.26		57.01	5.09	
Males FNR	25.41	4.93		32.66	5.33		23.76	5.26		42.99	5.09	
Males TNR	83.55	4.16		76.44	4.82		79.36	5.69		88.12	3.48	
Males FPR	16.45	4.16		23.56	4.82		20.64	5.69		11.88	3.48	
Males TPR	74.59	4.93		67.34	5.33		76.24	5.26		57.01	5.09	

Supplementary Table 5.0 - Experiment 3.1.2 – Comparison of evaluation metrics before and after balancing the training data

	Random Forest Classifier				Logistic Regression Classifier				Support Vector Machine				Gaussian Naive Bayes			
	Unbalanced Training Data		Balanced Training Data		Unbalanced Training Data		Balanced Training Data		Unbalanced Training Data		Balanced Training Data		Unbalanced Training Data		Balanced Trained Data	
	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
All Accuracy	78.17	2.36	81.66	2.33	71.31	2.37	74.53	1.96	79.40	2.50	83.30	1.75	71.53	2.61	74.75	1.97
All ROC_AUC	78.25	2.30	80.22	2.41	71.42	2.28	72.40	1.97	79.44	2.47	82.70	1.85	71.49	2.33	71.67	1.97
All Precision	82.65	3.69	84.80	3.38	77.04	3.98	78.52	4.30	80.46	3.95	82.71	3.84	85.98	4.12	85.28	3.80
All Recall	71.58	4.69	69.87	4.42	61.37	4.19	56.57	3.85	78.59	6.01	77.91	4.71	51.37	4.36	49.83	3.77
Females Accuracy	76.06	4.40	84.75	3.03	73.33	3.95	77.71	2.42	81.55	4.80	89.03	2.23	73.45	4.57	78.47	2.35
Females ROC_AUC	72.55	4.76	78.47	3.76	68.04	3.91	67.10	2.86	80.91	5.46	86.87	3.01	66.66	3.91	67.12	2.59
Females Precision	78.52	10.63	85.44	6.07	81.31	11.31	82.22	8.04	78.01	9.48	84.22	5.64	88.66	8.11	85.13	7.00
Females Recall	55.27	9.49	61.70	7.03	42.70	7.85	38.12	6.09	76.68	13.47	80.88	6.90	36.37	7.58	37.19	5.02
Males Accuracy	79.02	2.81	78.58	3.05	70.49	2.74	71.35	3.22	78.57	2.85	77.56	2.93	70.74	3.08	71.04	3.22
Males ROC_AUC	79.36	2.71	79.07	2.93	70.97	2.71	71.89	3.07	78.50	2.92	77.80	2.95	72.20	2.79	72.57	2.82
Males Precision	83.76	3.75	84.49	3.92	76.44	4.52	77.47	4.44	81.42	4.09	81.90	4.62	85.53	4.25	85.37	4.05
Males Recall	76.29	4.82	74.59	4.93	66.76	4.80	67.34	5.33	79.26	5.04	76.24	5.26	55.68	4.83	57.01	5.09

Supplementary Table 6.0: Summary Experiment 3 (Unbalanced Training Data, With Feature Selection)

	Random Forest Classifier			Logistic Regression Classifier			Support Vector Machine			Gaussian Naive Bayes		
	Mean	Standard Deviation	T Test Significance (Female to Male)	Mean	Standard Deviation	T Test Significance (Female to Male)	Mean	Standard Deviation	T Test Significance (Female to Male)	Mean	Standard Deviation	T Test Significance (Female to Male)
All Accuracy	76.88	2.68		70.34	2.31		70.24	2.36		71.56	2.60	
All FScore	75.65	2.94		65.88	2.86		64.00	3.24		64.57	3.62	
All ROC_AUC	76.92	2.65		70.35	2.21		70.38	2.25		71.67	2.24	
All Precision	80.32	4.24		77.38	4.23		81.75	4.61		86.07	3.68	
All Recall	71.72	4.10		57.56	3.84		52.77	3.98		51.86	4.50	
Females Accuracy	74.45	4.79	0.00	72.40	4.26	0.01	72.22	4.03	0.01	73.93	4.45	0.00
Females FScore	63.50	7.71	0.00	53.13	7.06	0.00	50.66	7.56	0.00	52.19	8.13	0.00
Females ROC_AUC	71.49	5.08	0.00	66.65	3.92	0.00	65.92	3.96	0.00	67.24	4.06	0.00
Females Precision	72.51	9.58	0.00	77.21	8.66	0.44	82.53	9.80	0.90	88.92	7.98	0.03
Females Recall	57.62	10.12	0.00	41.05	7.62	0.00	36.98	7.22	0.00	37.43	7.92	0.00
Females FNR	42.38	10.12	0.00	58.95	7.62	0.00	63.02	7.22	0.00	62.57	7.92	0.00
Females TNR	85.37	6.39	0.00	92.26	3.47	0.00	94.86	3.28	0.00	97.06	2.18	0.00
Females FPR	14.63	6.39	0.00	7.74	3.47	0.00	5.14	3.28	0.00	2.94	2.18	0.00
Females TPR	57.62	10.12	0.00	41.05	7.62	0.00	36.98	7.22	0.00	37.43	7.92	0.00
Males Accuracy	77.87	3.12		69.51	3.19		69.47	2.85		70.62	3.04	
Males FScore	78.87	3.14		68.92	3.34		67.16	3.36		67.48	3.98	
Males ROC_AUC	78.10	3.19		70.25	3.15		70.82	2.67		72.23	2.73	
Males Precision	82.37	4.43		77.45	4.66		81.66	4.77		85.51	4.30	
Males Recall	75.83	3.85		62.29	4.25		57.27	4.47		55.97	5.15	
Males FNR	24.17	3.85		37.71	4.25		42.73	4.47		44.03	5.15	
Males TNR	80.38	5.24		78.22	5.08		84.36	4.50		88.49	3.54	
Males FPR	19.62	5.24		21.78	5.08		15.64	4.50		11.51	3.54	
Males TPR	75.83	3.85		62.29	4.25		57.27	4.47		55.97	5.15	

Supplementary Table 7.0: Summary Experiment 4 (Balanced Training Data, With Feature Selection)

	Random Forest Classifier			Logistic Regression Classifier			Support Vector Machin			Gaussian Naive Bayes		
	Mean	Standard Deviation	T Test Significance (Female to Male)	Mean	Standard Deviation	T Test Significance (Female to Male)	Mean	Standard Deviation	T Test Significance (Female to Male)	Mean	Standard Deviation	T Test Significance (Female to Male)
All Accuracy	80.37	2.83		73.28	2.03		71.60	2.20		73.04	1.77	
All FScore	75.34	3.77		62.61	3.27		57.44	3.28		60.22	3.19	
All ROC_AUC	79.14	2.95		70.72	2.11		68.43	1.92		69.99	1.75	
All Precision	81.66	4.30		78.15	4.40		81.91	4.45		83.13	4.49	
All Recall	70.14	4.99		52.42	4.14		44.37	3.66		47.44	4.10	
Females Accuracy	83.18	3.55	0.00	76.69	2.55	0.00	74.70	3.06	0.00	75.36	2.89	0.00
Females FScore	70.21	6.99	0.00	53.18	5.80	0.00	46.78	5.96	0.00	45.78	6.45	0.00
Females ROC_AUC	78.02	4.71	0.46	67.48	3.15	0.00	64.32	2.97	0.00	64.09	3.10	0.00
Females Precision	78.65	6.76	0.00	71.91	7.85	0.00	73.34	8.33	0.00	76.37	9.99	0.00
Females Recall	63.99	9.10	0.00	42.59	6.27	0.00	34.74	5.85	0.00	33.05	5.84	0.00
Females FNR	36.01	9.10	0.00	57.41	6.27	0.00	65.26	5.85	0.00	66.95	5.84	0.00
Females TNR	92.05	2.72	0.00	92.37	2.27	0.00	93.90	2.23	0.01	95.12	2.35	0.00
Females FPR	7.95	2.72	0.00	7.63	2.27	0.00	6.10	2.23	0.00	4.88	2.35	0.00
Females TPR	63.99	9.10	0.00	42.59	6.27	0.00	34.74	5.85	0.00	33.05	5.84	0.00
Males Accuracy	77.56	3.23		69.88	2.92		68.50	2.93		70.73	2.73	
Males FScore	78.07	3.31		67.57	3.45		63.24	3.93		67.41	3.87	
Males ROC_AUC	77.98	3.24		71.05	2.79		70.27	2.67		72.25	2.33	
Males Precision	83.25	4.48		81.19	4.86		86.16	4.79		85.72	3.83	
Males Recall	73.69	4.33		58.10	4.50		50.11	4.35		55.83	5.34	
Males FNR	26.31	4.33		41.90	4.50		49.89	4.35		44.17	5.34	
Males TNR	82.26	5.02		84.00	4.40		90.43	3.39		88.68	3.56	
Males FPR	17.74	5.02		16.00	4.40		9.57	3.39		11.32	3.56	
Males TPR	73.69	4.33		58.10	4.50		50.11	4.35		55.83	5.34	

3.2 Supplementary, Analysis of Feature Selection

Supplementary Table 8.0 gives the feature rankings assigned by the RFE model when fitted to unbalanced data (Experiment 3) and balanced data (Experiment 4), focusing on RF classifiers.

Supplementary Table 8.0 – Comparison of RFE Feature Rankings when trained on unbalanced and balanced training data

Top 5 feature selected by Recursive Feature Elimination (RFE) on unbalanced and balanced training data			
Experiment 3 (Unbalanced Training Data)		Experiment 4 (Balanced Training Data)	
Rank	Feature	Rank	Feature
1.	A/G Ratio	1.	ALP (Alkphos Alkaline Phosphotase)
2.	ALP (Alkphos Alkaline Phosphotase)	2.	Gender
3.	SGOT Aspartate Aminotransferase	3.	SGOT Aspartate Aminotransferase
4.	SGPT Alamine Aminotransferate	4.	SGPT Alamine Aminotransferate
5.	Total Bilirubin (TB)	5.	Total Protiens (TP)