Supplementary Material for "Generative AI Mitigates Representation Bias and Improves Model Fairness Through Synthetic Health Data"

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Appendix A Distribution Plots for Sepsis

Fig. A1: Overlaid distribution plots of real data and CA-GAN synthetic data for each variable in the sepsis dataset.

Fig. A2: Overlaid distribution plots of real data and WGAN-GP* synthetic data for each variable in the sepsis dataset.

Fig. A3: Overlaid distribution plots of real data and SMOTE synthetic data for each variable in the sepsis dataset.

Appendix B Datasets

Table B1: Variables in the acute hypotension dataset. For each variable, the data type, the unit in which it is expressed, and the distribution statistics are presented.

Variable Name	Data Type	Unit	Descriptive Statistics	
Mean Arterial Pressure	numeric	mmHg	Median: 68.00 (Q1: 61.00, Q3: 76.00)	
Diastolic Blood Pressure	numeric	mmHg	Median: 54.00 (Q1: 47.00, Q3: 62.00)	
Systolic BP	numeric	mmHg	Median: 107.00 (Q1: 96.00, Q3: 120.00)	
Urine	numeric	mL	Median: 75.00 (Q1: 45.00, Q3: 140.00)	
Alanine Aminotransferase	numeric	IU/L	Median: 35.00 (Q1: 23.00, Q3: 35.00)	
Aspartate Aminotransferase	numeric	IU/L	Median: 50.00 (Q1: 33.00, Q3: 50.00)	
Partial Pressure of Oxygen	numeric	mmHg	Median: 102.00 (Q1: 99.00, Q3: 102.00)	
Lactate	numeric	mmol/L	Median: 1.80 (Q1: 1.20, Q3: 1.80)	
Serum Creatinine	numeric	mg/dL	Median: 1.10 (Q1: 0.80, Q3: 1.90)	
Fluid Boluses	categorical	mL	4 Classes	
			[0,250) : 95.75%;	[250,500) : 0.61%
			[500,1000) : 1.73%;	$\geq$ 1000 : 1.91%
Vasopressors	categorical	mcg/kg/min	4 Classes	
			0 : 81.95%;	(0,8.4) : 9.02%
			[8.4,20.28) : 4.51%;	$\geq$ 20.28 : 4.52%
Fraction of Inspired Oxygen	categorical	fraction	10 Classes	
			$\leq$ 0.2 : 0.44%;	0.2 : 0.45%
			0.3 : 5.29%;	0.4 : 15.52%
			0.5 : 61.64%;	0.6 : 4.36%
			0.7 : 2.78%;	0.8 : 1.43%
			0.9 : 1.42%;	1.0 : 6.67%
Glasgow Coma Scale Score	categorical	point	13 Classes	
			3 : 4.57%	4 : 0.72%
			5 : 0.44%	6 : 2.37%
			7 : 3.44%	8 : 4.03%
			9 : 3.63%	10 : 6.61%
			11 : 4.48%	12 : 1.22%
			13 : 3.23%	14 : 11.48%
			15 : 53.80%	
Urine Data Measured (M)	binary	-	False: 55.64%	True: 44.36%
ALT or AST (M)	binary	-	False: 97.73%	True: 2.27%
FiO2 (M)	binary	-	False: 88.80%	True: 11.20%
GCS (M)	binary	-	False: 78.06%	True: 21.94%
PaO2 (M)	binary	-	False: 95.45%	True: 4.55%
Lactic Acid (M)	binary	-	False: 95.61%	True: 4.39%
Serum Creatinine (M)	binary	-	False: 92.79%	True: 7.21%

B.1 Data preprocessing

Detailed description of the data preprocessing steps are available from our previous publication [1] in Section 1 of the supplementary material [2]. However, for completeness we highlight some of the main approaches. For the acute hypotension dataset we included adult patients (18 or over) in the MIMIC-III dataset with at least 24 hours of data, aggregating 48 hours of clinical variables from patients with seven or more mean arterial pressure (MAP) values of 65 mmHg or less, indicating acute hypotension. Missing values were replaced with the last available data, while an indicator variable was used to denote whether a value was measured or not. For the sepsis dataset we included adult patients only who had any suspicious infections based on history of administering

[1] Kuo, N.IH., Polizzotto, M.N., Finfer, S. et al. The Health Gym: synthetic health-related datasets for the development of reinforcement learning algorithms. Sci Data 9, 693 (2022). https://doi.org/10.1038/s41597-022-01784-7

[2] https://static-content.springer.com/esm/art%3A10.1038%2Fs41597-022-01784-7/MediaObjects/41597_2022_1784_MOESM4_ESM.pdf

Table B2: Variables in the sepsis dataset. For each variable, the data type, the unit in which it is expressed, and the distribution statistics are presented.

Variable Name	Data Type	Unit	Descriptive Statistics	
Age	numerical	years	Median: 66.95 (Q1: 54.21, Q3: 78.70)	
Heart Rate (HR)	numerical	bpm	Median: 86.75 (Q1: 75.40, Q3: 98.86)	
Systolic BP	numerical	mmHg	Median: 118.17 (Q1: 105.33, Q3: 134.20)	
Mean BP	numerical	mmHg	Median: 77.25 (Q1: 69.12, Q3: 87.00)	
Diastolic BP	numerical	mmHg	Median: 56.81 (Q1: 48.60, Q3: 65.67)	
Respiratory Rate (RR)	numerical	bpm	Median: 20.00 (Q1: 16.86, Q3: 23.83)	
Potassium (K)	numerical	meq/L	Median: 4.00 (Q1: 3.70, Q3: 4.30)	
Sodium (Na)	numerical	meq/L	Median: 139.00 (Q1: 136.00, Q3: 142.00)	
Chloride (Cl)	numerical	meq/L	Median: 105.00 (Q1: 101.00, Q3: 109.00)	
Calcium (Ca)	numerical	mg/dL	Median: 8.30 (Q1: 7.84, Q3: 8.74)	
Ionised Ca	numerical	mg/dL	Median: 1.13 (Q1: 1.08, Q3: 1.18)	
Carbon Dioxide (CO2)	numerical	meq/L	Median: 26.00 (Q1: 22.75, Q3: 29.00)	
Albumin	numerical	g/dL	Median: 2.90 (Q1: 2.50, Q3: 3.40)	
Hemoglobin (Hb)	numerical	g/dL	Median: 10.00 (Q1: 9.04, Q3: 11.20)	
pH	numerical	-	Median: 7.40 (Q1: 7.35, Q3: 7.44)	
Arterial Base Excess	numerical	meq/L	Median: 0.00 (Q1: -2.00, Q3: 3.15)	
Bicarbonate (HCO3)	numerical	meq/L	Median: 25.00 (Q1: 22.00, Q3: 28.00)	
FiO2	numerical	fraction	Median: 0.40 (Q1: 0.40, Q3: 0.50)	
Glucose	numerical	mg/dL	Median: 129.67 (Q1: 109.00, Q3: 157.60)	
Blood Urea Nitrogen	numerical	mg/dL	Median: 24.00 (Q1: 15.00, Q3: 41.00)	
Creatinine	numerical	mg/dL	Median: 1.00 (Q1: 0.70, Q3: 1.60)	
Magnesium (Mg)	numerical	mg/dL	Median: 2.03 (Q1: 1.90, Q3: 2.27)	
SGOT	numerical	u/L	Median: 41.00 (Q1: 25.00, Q3: 86.00)	
SGPT	numerical	u/L	Median: 32.00 (Q1: 18.00, Q3: 69.00)	
Total Bilirubin	numerical	mg/dL	Median: 0.70 (Q1: 0.40, Q3: 1.80)	
White Blood Cell Count	numerical	E9/L	Median: 11.20 (Q1: 8.20, Q3: 15.20)	
Platelets Count	numerical	E9/L	Median: 207.85 (Q1: 141.00, Q3: 296.00)	
paO2	numerical	mmHg	Median: 105.25 (Q1: 82.57, Q3: 140.00)	
paCO2	numerical	mmHg	Median: 40.22 (Q1: 35.25, Q3: 46.09)	
Lactate	numerical	mmol/L	Median: 1.60 (Q1: 1.10, Q3: 2.30)	
Total Input Fluids	numerical	mL	Median: 6569.08 (Q1: 2540.00, Q3: 13047.66)	
Input 4H	numerical	mL	Median: 80.01 (Q1: 20.34, Q3: 327.50)	
Max Vasopressors in 4H	numerical	mcg/kg/min	Median: 0.0002 (Q1: 0.00, Q3: 0.0017)	
Total Volume Output	numerical	mL	Median: 3893.00 (Q1: 1300.00, Q3: 10070.00)	
Output 4H	numerical	mL	Median: 248.00 (Q1: 105.00, Q3: 460.00)	
Gender	binary	-	Male: 56.46%	Female: 43.54%
Readmission of Patient	binary	-	False: 67.75%	True: 32.25%
Mechanical Ventilation	binary	-	False: 46.89%	True: 53.11%
Temperature (Temp)	categorical	Celsius	3 Classes	
			<35.05: 8.64%	
			35.05-38: 79.65%	
			>38: 11.71%	
GCS	categorical	point	13 Classes	
			3: 5.10%	4: 0.76%
			5: 0.93%	6: 4.51%
			7: 3.72%	8: 4.12%
			9: 5.17%	10: 7.93%
			11: 9.68%	12: 3.98%
			13: 3.45%	14: 13.03%
			15: 37.61%	
Pulse Oximetry Saturation	categorical	%	10 Classes	
			[50.00,94.00): 9.34%	[94.00,95.29): 10.54%
			[95.29,96.14): 10.11%	[96.14,96.80): 9.49%
			[96.80,97.40): 9.77%	[97.40,98.00): 8.70%
			[98.00,98.67): 12.05%	[98.67,99.25): 9.96%
			[99.25,99.83): 9.99%	[99.83,100.00]: 10.05%
Partial Thromboplastin Time	categorical	s	10 Classes	
			[0.00,24.50): 9.69%	[24.50,26.50): 9.92%
			[26.50,28.10): 10.35%	[28.10,29.74): 10.02%
			[29.74,31.70): 9.76%	[31.70,34.20): 10.09%
			[34.20,37.60): 10.08%	[37.60,44.50): 10.04%
			[44.50,60.90): 10.04%	[60.90,162.40]: 9.99%
Prothrombin Time	categorical	s	10 Classes	
			[8.50,12.04): 10.00%	[12.04,12.90): 9.77%
			[12.90,13.40): 9.68%	[13.40,13.80): 9.67%
			[13.80,14.30): 10.54%	[14.30,14.90): 10.03%
			[14.90,15.80): 10.14%	[15.80,17.40): 9.99%
			[17.40,21.54): 10.20%	[21.54,193]: 9.98%
INR	categorical	-	10 Classes	
			[0.10,1.04): 10.00%	[1.04,1.10): 0.48%
			[1.10,1.19): 17.55%	[1.19,1.20): 2.15%
			[1.20,1.30): 16.88%	[1.30,1.31): 11.23%
			[1.31,1.46): 11.68%	[1.46,1.66): 10.02%
			[1.66,2.2): 9.79%	[2.2,19.8]: 10.22%

antibiotics. We included all the variables from at least 44 hours before the suspected infection and up to 28 hours after. The missing data was imputed using nearest neighbour method. More detailed information is available in https:

//static-content.springer.com/esm/art%3A10.1038%2Fs41597-022-01784-7/MediaObjects/41597_2022_1784_MOESM4_ESM.pdf

Appendix C UMAP and t-SNE parameters

In this study, we used t-SNE and UMAP algorithms to perform dimensionality reduction on our datasets and highlight the differences between the results of the three methods under analysis. The following parameters were used for each algorithm:

t-SNE:

Library: scikit-learn version 1.2.2
Parameters for sepsis: $n\_components = 2$, $n\_iter = 500$, $learning\_rate = 100$, $perplexity = 50$
Parameters for acute hypotension: $n\_components = 2$, $n\_iter = 100$, $learning\_rate = 1000$, $perplexity = 30$

UMAP:

Library: umap-learn version 0.5.3
Parameters: $n\_neighbors = 5$, $spread = 5$, $min\_dist = 0.5$

Appendix D Joint distributions of variables

We have carried out an analysis of a set of variables that are clinically known to follow a joint distribution, namely systolic, diastolic and mean arterial blood pressure. This was to investigate whether CA-GAN can capture joint distributions of variables and whether synthetic data are clinically meaningful, where we know that systolic blood pressure is always higher than diastolic blood pressure. Using a scatter plot in Figure D4 we show that the joint distribution of real data is similar to that of synthetic data.

Following from this, we have also implemented several sanity checks based on clinical knowledge to ensure that the generated synthetic data is clinically meaningful. In this respect, we have performed checks to investigate whether systolic BP values are always lower than diastolic. From our analysis, in the real sepsis dataset, 99.94% of values of these variables were correct; that is, systolic values were always lower than the diastolic values. In the synthetic sepsis dataset, this figure was 99.93%, with only 0.01% difference between the real and the synthetic dataset. On the other hand for the hypotension dataset there were 99.86% correct values of systolic and diastolic variables versus 99.84% in the synthetic dataset, representing a 0.02% difference. This analysis suggests that our architecture captures the structure of the real data quite well.

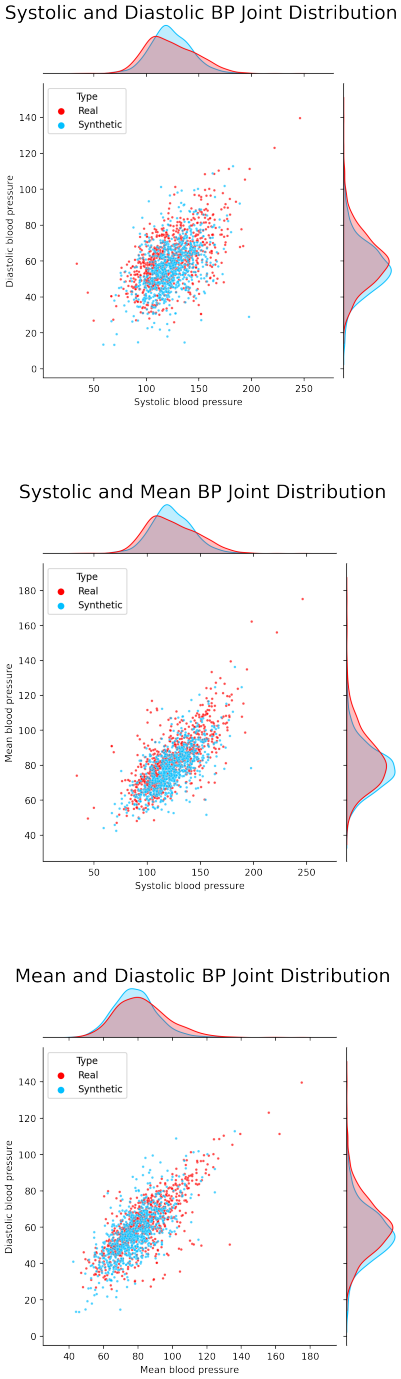


Fig. D4: Joint distribution plot of real sepsis data and CA-GAN synthetic data for the variables *Systolic blood pressure*, *Diastolic blood pressure* and *Mean arterial pressure*.

Appendix E Summary of distance metrics

Table E3: Statistics for KL-Divergence and Maximum Mean Discrepancy between the distribution of real and synthetic data.

	KL-divergence			MMD		
	SMOTE	WGAN-GP*	**CA-GAN**	SMOTE	WGAN-GP*	**CA-GAN**
MEDIAN	0.03407	0.02711	0.00629	0.00752	0.00217	0.00089
MEAN	0.05754	0.13518	0.14128	0.01500	0.05861	0.04790
STD DEV	0.07222	0.22330	0.31578	0.02385	0.09311	0.08457
MAX	0.28191	0.91622	1.36841	0.09954	0.25091	0.24806
MIN	0.00068	0.00010	0.00005	0.00047	0.00001	0.00001

(a) Acute hypotension data

	KL-divergence			MMD		
	SMOTE	WGAN-GP*	**CA-GAN**	SMOTE	WGAN-GP*	**CA-GAN**
MEDIAN	0.02296	0.06105	0.02292	0.00349	0.01299	0.00377
MEAN	0.09946	0.09282	0.06656	0.00583	0.03848	0.02505
STD DEV	0.29030	0.09704	0.08906	0.00702	0.13482	0.11603
MAX	1.88754	0.33564	0.39555	0.02948	0.90096	0.77536
MIN	0.00035	0.00240	0.00199	0.00002	0.00041	0.00003

(b) Sepsis data

Appendix F Description of Downstream Regression Task

For this task, the BiLSTM is trained on the first 20 hours for hypotension and 10 hours for sepsis of the patients' values to predict the next hour, using a sliding window approach. To ensure the fairness of our result, 15% of the time series data points of Black patients and a proportional representation of different genders were set apart as a test set. To account for the stochasticity of the models, we generated five synthetic datasets with CA-GAN. Then, we trained 5 BiLSTM models on each dataset for a total of 25 BiLSTM models (5x(5 per dataset)). The predictions of the trained models were then compared with the test dataset, and the resulting error was averaged across the five models and, subsequently, the five datasets.

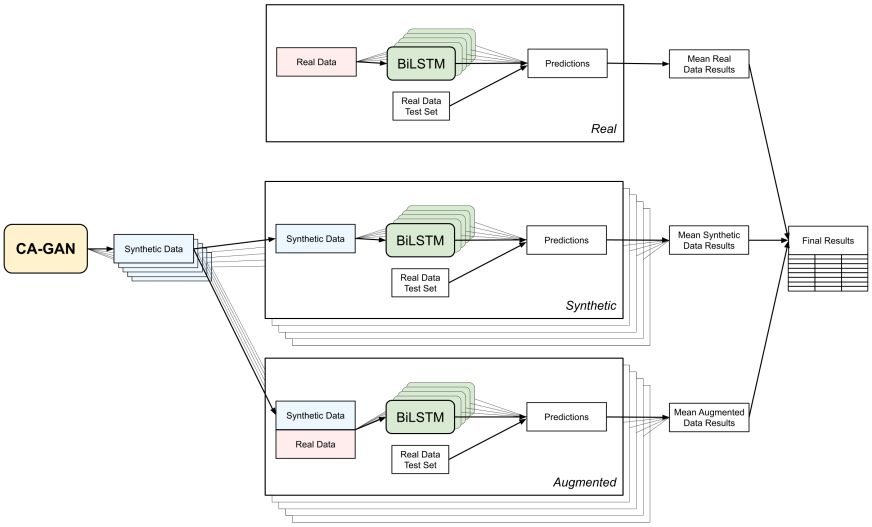


Fig. F5: Diagram of BiLSTM Model Training for Continuous Variable Prediction.

Appendix G UMAP Plots

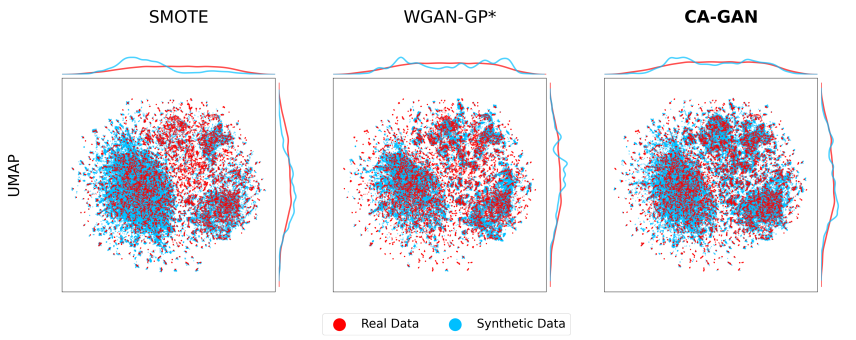


Fig. G6: UMAP two-dimensional representations of the acute hypotension dataset for Black patients.

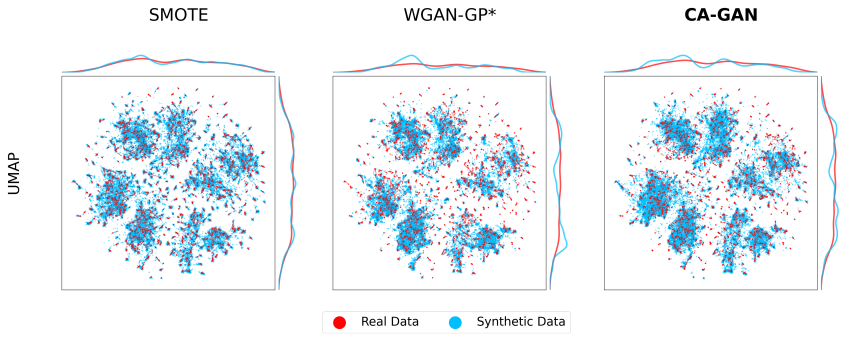
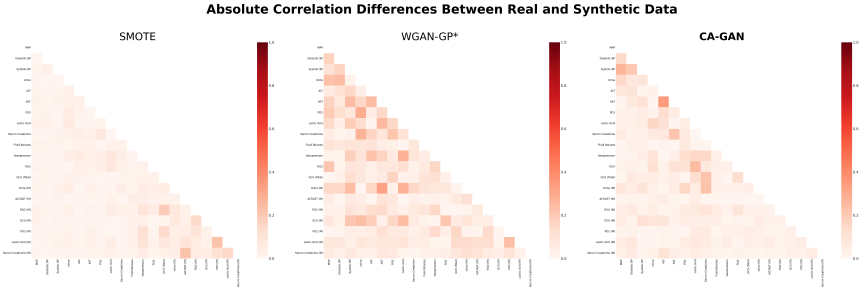
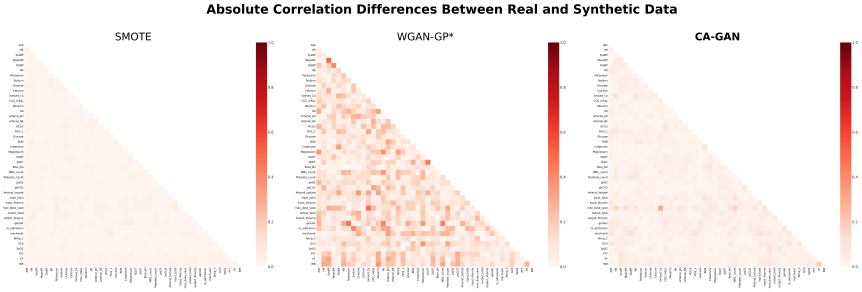


Fig. G7: UMAP two-dimensional representations of the sepsis dataset for Black patients.

Appendix H Absolute Differences in Correlations



(a) Acute hypotension data



(b) Sepsis data

Fig. H8: Absolute difference in correlations between real data and the synthetic data generated with SMOTE, WGAN-GP*, and CA-GAN.