ABG-VBG Analysis

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1 Data Pre-processing

This code pulls in the master database (a STATA file) and does some initial cleaning - this will only need to be run once, and then the data can be accessed in the usual way.

1.0.1 Package Set Up

1.1 Helper functions for model diagnostics

1.1.1 Rendering and Diagram Setup

1.2 1) Seed escrow (reproducibility anchors)

1.2.1 Rendering support information

1.2.2 Input Data Formatting

Converts the data from a STATA format to rdata if the rdata file does not exist. If it does already exist, it just loads that.

1.2.3 Configuration for the IPW models

1.2.4 Creating subset_data

Table 1: Run metadata (pilot vs full)

run_id	run_mode	pilot_frac	mi_batch_threshold	full_n	subset_n
20260129_163529	pilot	0.02	5000	833476	10303

1.2.5 Generating Codebook for the Full Dataset

1.2.6 Outcome Variable Creation

1.3 2) Baseline tables

1.3.1 2.1 Table 1A and 1B:

1.3.2 2.2 Table 1 (Overall ABG/VBG status)

1.3.3 2.3 Table 2 (CO2 category within cohorts)

1.4 3) Three-level PCO2 categories (unweighted)

Three groups using low/normal/high CO2 categories

Table 2: Table 1A: ABG cohorts

Variable	**No ABG** N = 6,595	**ABG** N = 3,708
age_at_encounter	58.2 ± 17.8; 0.0/6,595.0 missing (0.0%)	61.2 ± 17.1; 0.0/3,708.0 missing (0.0%)
curr_bmi	32.6 ± 8.7; 3,684.0/6,595.0 missing (55.9%)	29.1 ± 7.2; 2,153.0/3,708.0 missing (58.1%)
sex_label		
Female	3,457 (52%)	1,670 (45%)
Male	3,138 (48%)	2,038 (55%)
race_ethnicity_label		
White	4,073 (62%)	2,441 (66%)
Black or African American	1,196 (18%)	540 (15%)
Hispanic	485 (7.4%)	188 (5.1%)
Asian	99 (1.5%)	73 (2.0%)
American Indian	33 (0.5%)	39 (1.1%)
Pacific Islander	14 (0.2%)	4 (0.1%)
Unknown	695 (11%)	423 (11%)
location_label		
South	2,735 (41%)	2,070 (56%)
Northeast	1,869 (28%)	708 (19%)
Midwest	481 (7.3%)	303 (8.2%)
West	1,510 (23%)	627 (17%)
osa_label	1,217 (18%)	559 (15%)
asthma_label	956 (14%)	421 (11%)
copd_label	1,159 (18%)	834 (22%)
chf_label	1,184 (18%)	854 (23%)
nmd_label	237 (3.6%)	171 (4.6%)
phtn_label	451 (6.8%)	364 (9.8%)
ckd_label	1,071 (16%)	723 (19%)
diabetes_label	1,913 (29%)	1,083 (29%)
encounter_type_label		
Emergency	2,838 (43%)	578 (16%)
Inpatient	3,757 (57%)	3,130 (84%)

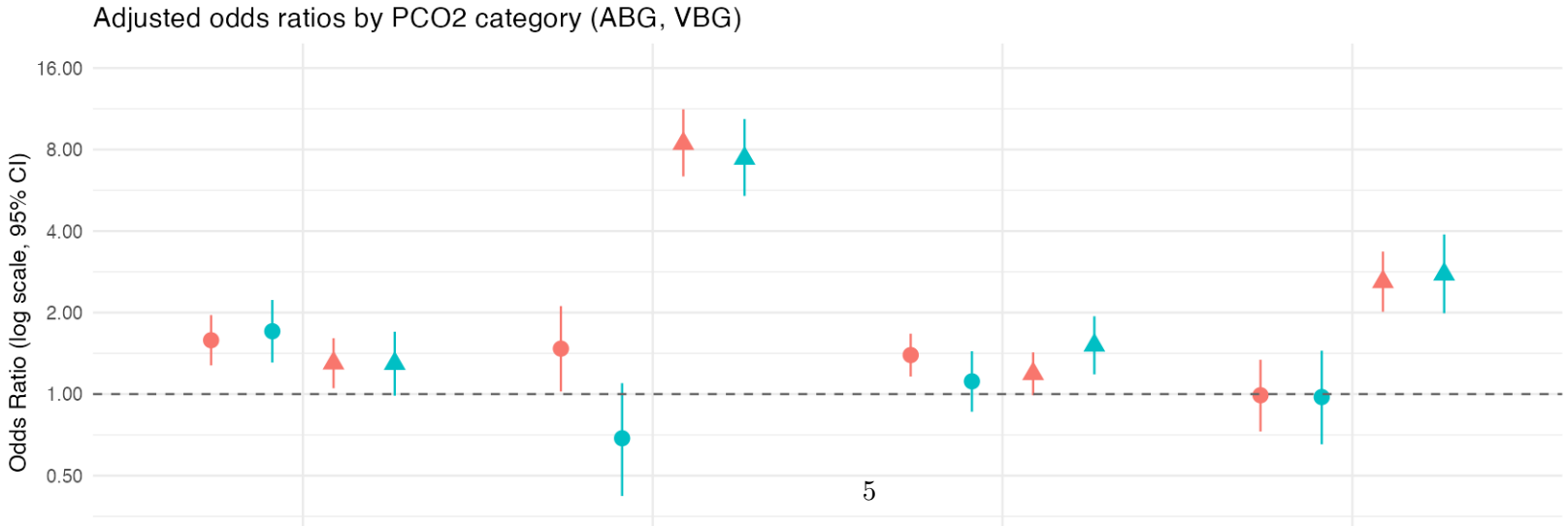


Table 3: Table 1B: VBG cohorts

Variable	**No VBG** N = 7,369	**VBG** N = 2,934
age_at_encounter	59.4 ± 17.7; 0.0/7,369.0 missing (0.0%)	59.2 ± 17.5; 0.0/2,934.0 missing (0.0%)
curr_bmi	31.9 ± 8.5; 3,845.0/7,369.0 missing (52.2%)	29.2 ± 7.4; 1,992.0/2,934.0 missing (67.9%)
sex_label		
Female	3,747 (51%)	1,380 (47%)
Male	3,622 (49%)	1,554 (53%)
race_ethnicity_label		
White	4,932 (67%)	1,582 (54%)
Black or African American	1,189 (16%)	547 (19%)
Hispanic	466 (6.3%)	207 (7.1%)
Asian	111 (1.5%)	61 (2.1%)
American Indian	36 (0.5%)	36 (1.2%)
Pacific Islander	15 (0.2%)	3 (0.1%)
Unknown	620 (8.4%)	498 (17%)
location_label		
South	3,909 (53%)	896 (31%)
Northeast	1,344 (18%)	1,233 (42%)
Midwest	506 (6.9%)	278 (9.5%)
West	1,610 (22%)	527 (18%)
osa_label	1,307 (18%)	469 (16%)
asthma_label	1,009 (14%)	368 (13%)
copd_label	1,408 (19%)	585 (20%)
chf_label	1,422 (19%)	616 (21%)
nmd_label	302 (4.1%)	106 (3.6%)
phtn_label	555 (7.5%)	260 (8.9%)
ckd_label	1,201 (16%)	593 (20%)
diabetes_label	2,054 (28%)	942 (32%)
encounter_type_label		
Emergency	2,501 (34%)	915 (31%)
Inpatient	4,868 (66%)	2,019 (69%)

1.5 4) Restricted cubic spline regressions (unweighted)

Spline curves are shown as odds ratios relative to CO2_ref (midpoint of the normal range), holding covariates at the reference profile.

Table 4: **Table 1. Baseline summary: Everyone, ABG status, and VBG status**

Variable	Everyone	**Did not get ABG** N = 6,595	**Did get ABG** N = 3,708	**Did not get VBG** N = 7,369	**Did get VBG** N = 2,934
age_at_encounter	59.3 ± 17.6; 0.0/10,303.0 missing (0.0%)	58.2 ± 17.8; 0.0/6,595.0 missing (0.0%)	61.2 ± 17.1; 0.0/3,708.0 missing (0.0%)	59.4 ± 17.7; 0.0/7,369.0 missing (0.0%)	59.2 ± 17.5; 0.0/2,934.0 missing (0.0%)
curr_bmi	31.3 ± 8.4; 5,837.0/10,303.0 missing (56.7%)	32.6 ± 8.7; 3,684.0/6,595.0 missing (55.9%)	29.1 ± 7.2; 2,153.0/3,708.0 missing (58.1%)	31.9 ± 8.5; 3,845.0/7,369.0 missing (52.2%)	29.2 ± 7.4; 1,992.0/2,934.0 missing (67.9%)
sex_label					
Female	5,127 (50%)	3,457 (52%)	1,670 (45%)	3,747 (51%)	1,380 (47%)
Male	5,176 (50%)	3,138 (48%)	2,038 (55%)	3,622 (49%)	1,554 (53%)
race_ethnicity_label					
White	6,514 (63%)	4,073 (62%)	2,441 (66%)	4,932 (67%)	1,582 (54%)
Black or African American	1,736 (17%)	1,196 (18%)	540 (15%)	1,189 (16%)	547 (19%)
Hispanic	673 (6.5%)	485 (7.4%)	188 (5.1%)	466 (6.3%)	207 (7.1%)
Asian	172 (1.7%)	99 (1.5%)	73 (2.0%)	111 (1.5%)	61 (2.1%)
American Indian	72 (0.7%)	33 (0.5%)	39 (1.1%)	36 (0.5%)	36 (1.2%)
Pacific Islander	18 (0.2%)	14 (0.2%)	4 (0.1%)	15 (0.2%)	3 (0.1%)
Unknown	1,118 (11%)	695 (11%)	423 (11%)	620 (8.4%)	498 (17%)
location_label					
South	4,805 (47%)	2,735 (41%)	2,070 (56%)	3,909 (53%)	896 (31%)
Northeast	2,577 (25%)	1,869 (28%)	708 (19%)	1,344 (18%)	1,233 (42%)
Midwest	784 (7.6%)	481 (7.3%)	303 (8.2%)	506 (6.9%)	278 (9.5%)
West	2,137 (21%)	1,510 (23%)	627 (17%)	1,610 (22%)	527 (18%)
osa_label	1,776 (17%)	1,217 (18%)	559 (15%)	1,307 (18%)	469 (16%)
asthma_label	1,377 (13%)	956 (14%)	421 (11%)	1,009 (14%)	368 (13%)
copd_label	1,993 (19%)	1,159 (18%)	834 (22%)	1,408 (19%)	585 (20%)
chf_label	2,038 (20%)	1,184 (18%)	854 (23%)	1,422 (19%)	616 (21%)
nmd_label	408 (4.0%)	237 (3.6%)	171 (4.6%)	302 (4.1%)	106 (3.6%)
phtn_label	815 (7.9%)	451 (6.8%)	364 (9.8%)	555 (7.5%)	260 (8.9%)
ckd_label	1,794 (17%)	1,071 (16%)	723 (19%)	1,201 (16%)	593 (20%)
diabetes_label	2,996 (29%)	1,913 (29%)	1,083 (29%)	2,054 (28%)	942 (32%)
encounter_type_label					
Emergency	3,416 (33%)	2,838 (43%)	578 (16%)	2,501 (34%)	915 (31%)
Inpatient	6,887 (67%)	3,757 (57%)	3,130 (84%)	4,868 (66%)	2,019 (69%)

Table 5: **Table 2. Baseline summary by CO2 category within ABG and VBG cohorts**

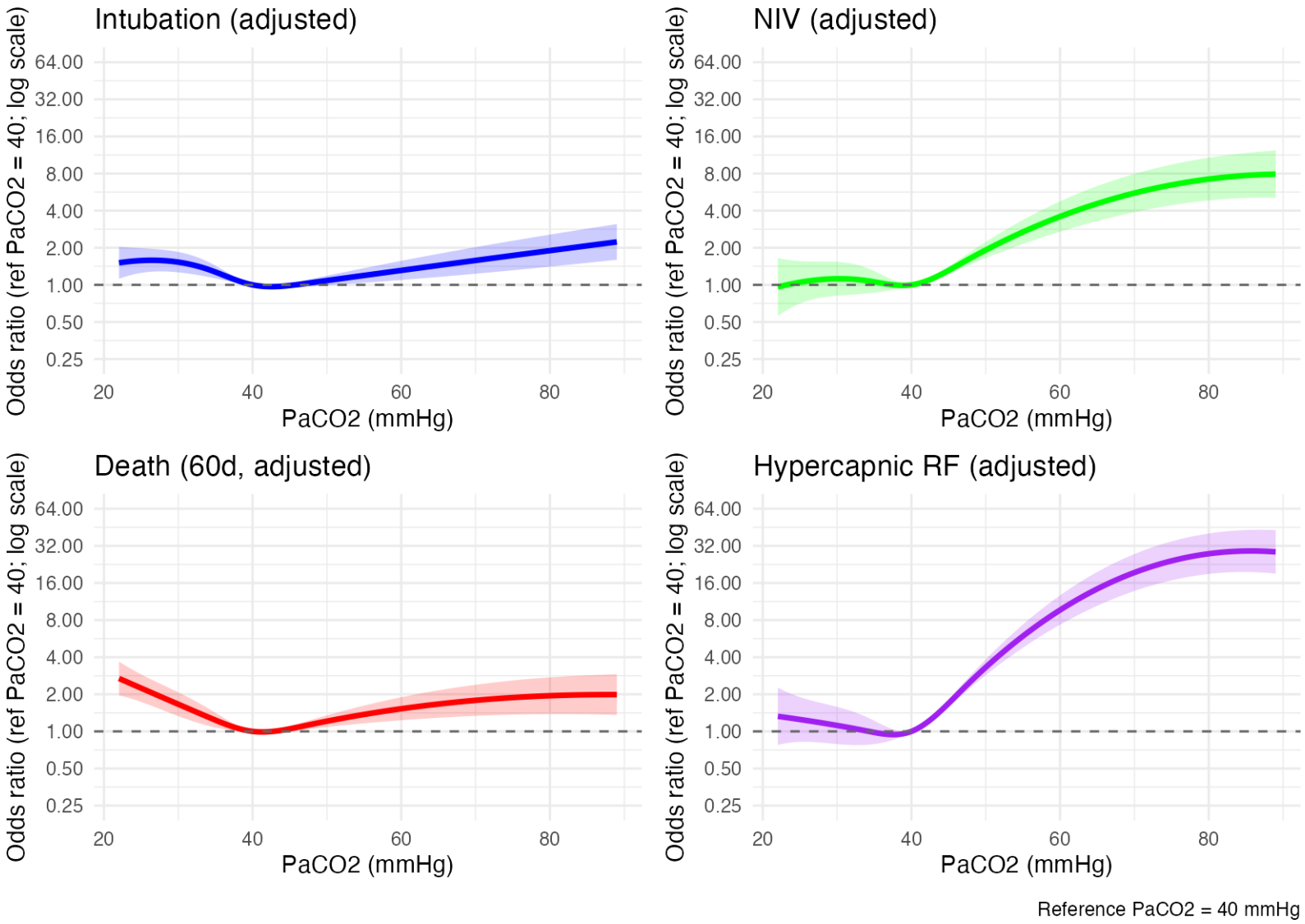
Variable	**Normal**	**Low**	**High**	**Normal**	**Low**	**High**
age_at_encounter	61.4 ± 16.9; 0.0/1,651.0 missing (0.0%)	60.1 ± 17.7; 0.0/984.0 missing (0.0%)	62.0 ± 16.7; 0.0/1,073.0 missing (0.0%)	58.0 ± 17.7; 0.0/1,304.0 missing (0.0%)	58.9 ± 17.9; 0.0/825.0 missing (0.0%)	61.4 ± 16.6; 0.0/805.0 missing (0.0%)
curr_bmi	28.9 ± 6.9; 929.0/1,651.0 missing (56.3%)	28.4 ± 7.0; 591.0/984.0 missing (60.1%)	29.9 ± 7.8; 633.0/1,073.0 missing (59.0%)	29.6 ± 7.1; 918.0/1,304.0 missing (70.4%)	28.5 ± 7.0; 504.0/825.0 missing (61.1%)	29.4 ± 8.2; 570.0/805.0 missing (70.8%)
sex_label						
Female	741 (45%)	444 (45%)	485 (45%)	646 (50%)	381 (46%)	353 (44%)
Male	910 (55%)	540 (55%)	588 (55%)	658 (50%)	444 (54%)	452 (56%)
race_ethnicity_label						
White	1,081 (65%)	622 (63%)	738 (69%)	682 (52%)	426 (52%)	474 (59%)
Black or African American	248 (15%)	142 (14%)	150 (14%)	242 (19%)	146 (18%)	159 (20%)
Hispanic	85 (5.1%)	55 (5.6%)	48 (4.5%)	102 (7.8%)	69 (8.4%)	36 (4.5%)
Asian	24 (1.5%)	29 (2.9%)	20 (1.9%)	29 (2.2%)	16 (1.9%)	16 (2.0%)
American Indian	22 (1.3%)	13 (1.3%)	4 (0.4%)	15 (1.2%)	17 (2.1%)	4 (0.5%)
Pacific Islander	3 (0.2%)	1 (0.1%)	0 (0%)	1 (<0.1%)	1 (0.1%)	1 (0.1%)
Unknown	188 (11%)	122 (12%)	113 (11%)	233 (18%)	150 (18%)	115 (14%)
location_label						
South	943 (57%)	547 (56%)	580 (54%)	407 (31%)	214 (26%)	275 (34%)
Northeast	283 (17%)	153 (16%)	272 (25%)	580 (44%)	316 (38%)	337 (42%)
Midwest	143 (8.7%)	78 (7.9%)	82 (7.6%)	117 (9.0%)	62 (7.5%)	99 (12%)
West	282 (17%)	206 (21%)	139 (13%)	200 (15%)	233 (28%)	94 (12%)
osa_label	217 (13%)	110 (11%)	232 (22%)	189 (14%)	117 (14%)	163 (20%)
asthma_label	167 (10%)	100 (10%)	154 (14%)	148 (11%)	114 (14%)	106 (13%)
copd_label	308 (19%)	152 (15%)	374 (35%)	202 (15%)	143 (17%)	240 (30%)
chf_label	341 (21%)	197 (20%)	316 (29%)	231 (18%)	169 (20%)	216 (27%)
nmd_label	80 (4.8%)	39 (4.0%)	52 (4.8%)	39 (3.0%)	25 (3.0%)	42 (5.2%)
phtn_label	136 (8.2%)	82 (8.3%)	146 (14%)	91 (7.0%)	63 (7.6%)	106 (13%)
ckd_label	320 (19%)	195 (20%)	208 (19%)	231 (18%)	210 (25%)	152 (19%)
diabetes_label	481 (29%)	271 (28%)	331 (31%)	381 (29%)	312 (38%)	249 (31%)
encounter_type_label						
Emergency	253 (15%)	135 (14%)	190 (18%)	452 (35%)	242 (29%)	221 (27%)
Inpatient	1,398 (85%)	849 (86%)	883 (82%)	852 (65%)	583 (71%)	584 (73%)
paco2	39.7 ± 2.9; 0.0/1,651.0 missing (0.0%)	29.5 ± 4.4; 0.0/984.0 missing (0.0%)	60.1 ± 21.2; 0.0/1,073.0 missing (0.0%)			
vbg_co2				44.6 ± 3.1; 0.0/1,304.0 missing (0.0%)	33.2 ± 5.1; 0.0/825.0 missing (0.0%)	62.0 ± 14.0; 0.0/805.0 missing (0.0%)

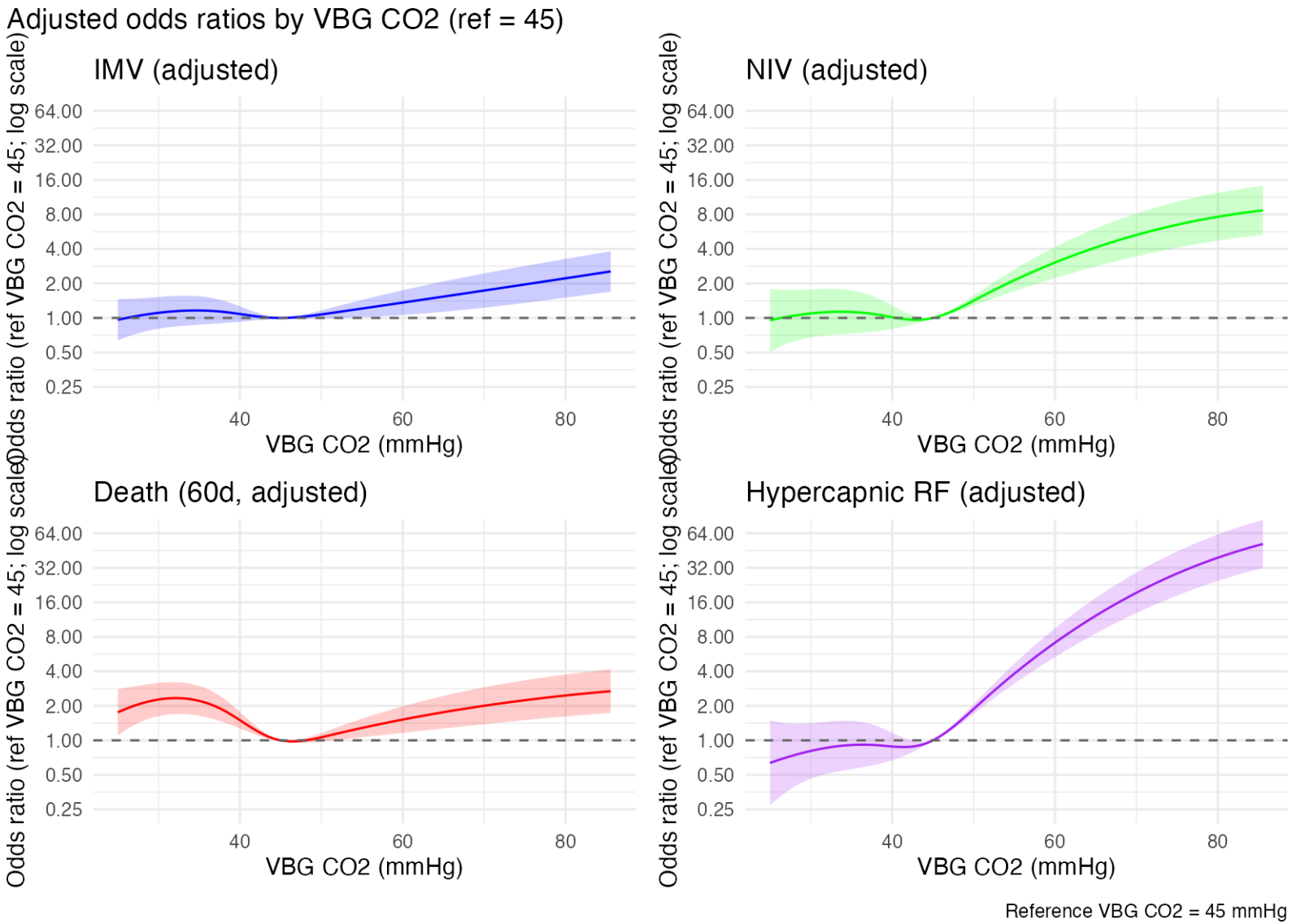
Table 6: Table 2a. Crude outcomes by CO2 category

Cohort	Outcome	Normal	Low	High
ABG	IMV	373/1651 (22.6%)	287/984 (29.2%)	277/1073 (25.8%)
ABG	NIV	122/1651 (7.4%)	74/984 (7.5%)	164/1073 (15.3%)
ABG	Death (60d)	238/1651 (14.4%)	199/984 (20.2%)	198/1073 (18.5%)
ABG	Hypercapnic RF	67/1651 (4.1%)	58/984 (5.9%)	270/1073 (25.2%)
VBG	IMV	168/1304 (12.9%)	128/825 (15.5%)	156/805 (19.4%)
VBG	NIV	66/1304 (5.1%)	47/825 (5.7%)	106/805 (13.2%)
VBG	Death (60d)	136/1304 (10.4%)	140/825 (17.0%)	120/805 (14.9%)
VBG	Hypercapnic RF	53/1304 (4.1%)	27/825 (3.3%)	191/805 (23.7%)

1.5.1 4.1 Unweighted, Restricted Cubic Spline Regression - ABG by PaCO2

1.5.2 4.2 Unweighted, Restricted Cubic Spline - VBG




Adjusted odds ratios by VBG CO2 (ref = 45)
IMV (adjusted)
NIV (adjusted)
Death (60d, adjusted)
Hypercapnic RF (adjusted)
Odds ratio (ref VBG CO2 = 45; log scale)
64.00
32.00
16.00
8.00
4.00
2.00
1.00
0.50
0.25
40
60
80
VBG CO2 (mmHg)
Reference VBG CO2 = 45 mmHg

2 Inverse Propensity Weighting

IPW done using Gradient Boosting Methods (GBM) - a type of decision-tree based machine learning. "***Random forests and GBM are designed to automatically include relevant interactions for variables included in the model.*** As such, using a GBM to estimate the PS model, can reduce model misspecification, since ***the analyst is not required to identify relevant interactions or nonlinearities."*** from this citation: PMID: 39947224https://pmc.ncbi.nlm.nih.gov/articles/PMC11825193/

Current propensity score uses `covars_gbm` (demographics, comorbidities, encounter type, vitals, labs) as defined above; in this block only `encounter_type` is explicitly factored before weighting.

Note: for all these, I suggested new GBM adjustments that accomplish the following:

1. Smaller GBM & balance-based stopping (stop.method = "smd.max") → faster fit, avoids over-fitting, lighter tails (which lead to extreme weights that are problematic).
2. Target balance compares weighted treated cohort to the full sample; aim for |SMD| < 0.1.
3. Weight stabilization (divide by mean) mitigates a few huge weights. We use one-sided truncation at very small propensities (caps large weights only).
4. Uses robust variance estimation (e.g. allows the variances to change by PaCO2) for IP-weighted GLM; works with splines via rcs(). This is a bit nuanced but I think good to change even though it adds complexity
5. Deterministic seed ensures result replication.

2.0.1 5.1 ABG IPW weighting and diagnostics

GBM tuning is shared across ABG and VBG via `gbm_params` to keep symmetry; update there if needed.

Inverse Propensity-Weighted Logistic Regressions with CO2 predictor represented as a restricted cubic spline.

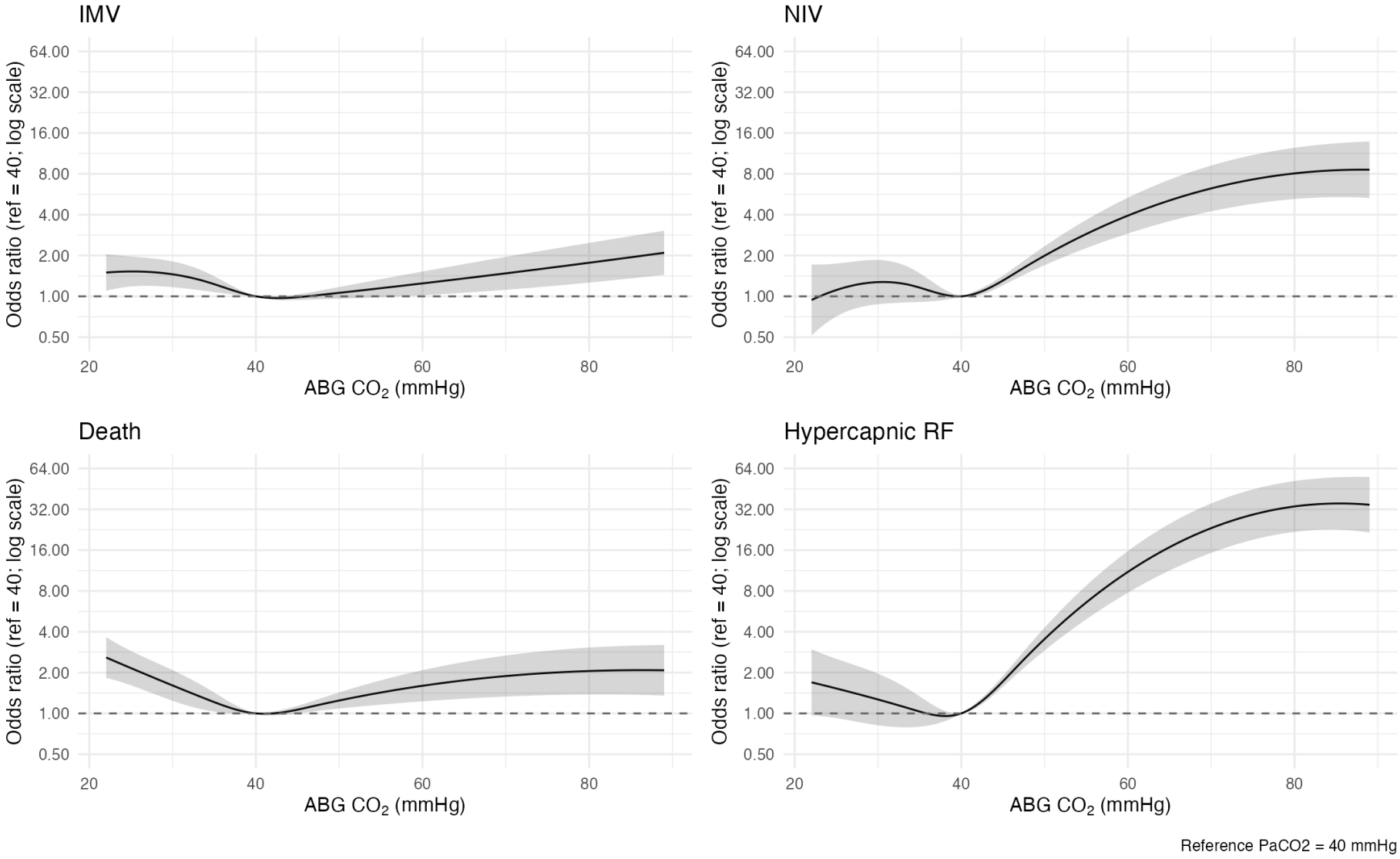
These are covariate-adjusted outcome models (outcome ~ spline(CO2) + X), fit separately for ABG and VBG cohorts using survey::svyglm with robust (design-based) SEs. Spline curves are shown as odds ratios relative to CO2_ref (midpoint of the normal range).

2.0.2 5.2 ABG IPW spline models

Restricting plots bewtween 0.02 and 0.98

2.0.3 5.3 ABG IPW spline models (2–98th percentile)

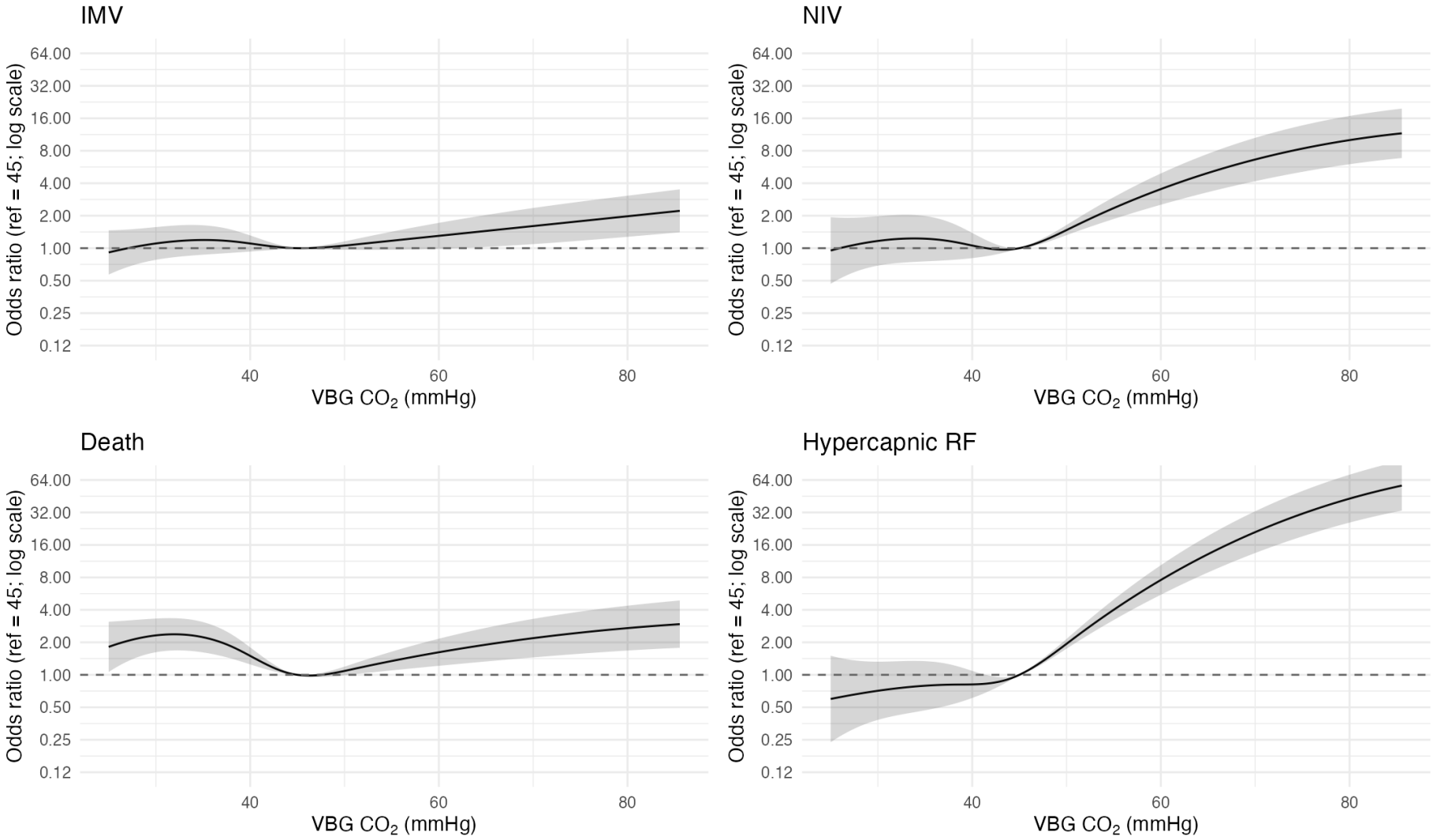
Propensity-weighted adjusted odds ratios by ABG CO2 (ref = 40; conditional on X; 2–98% range)



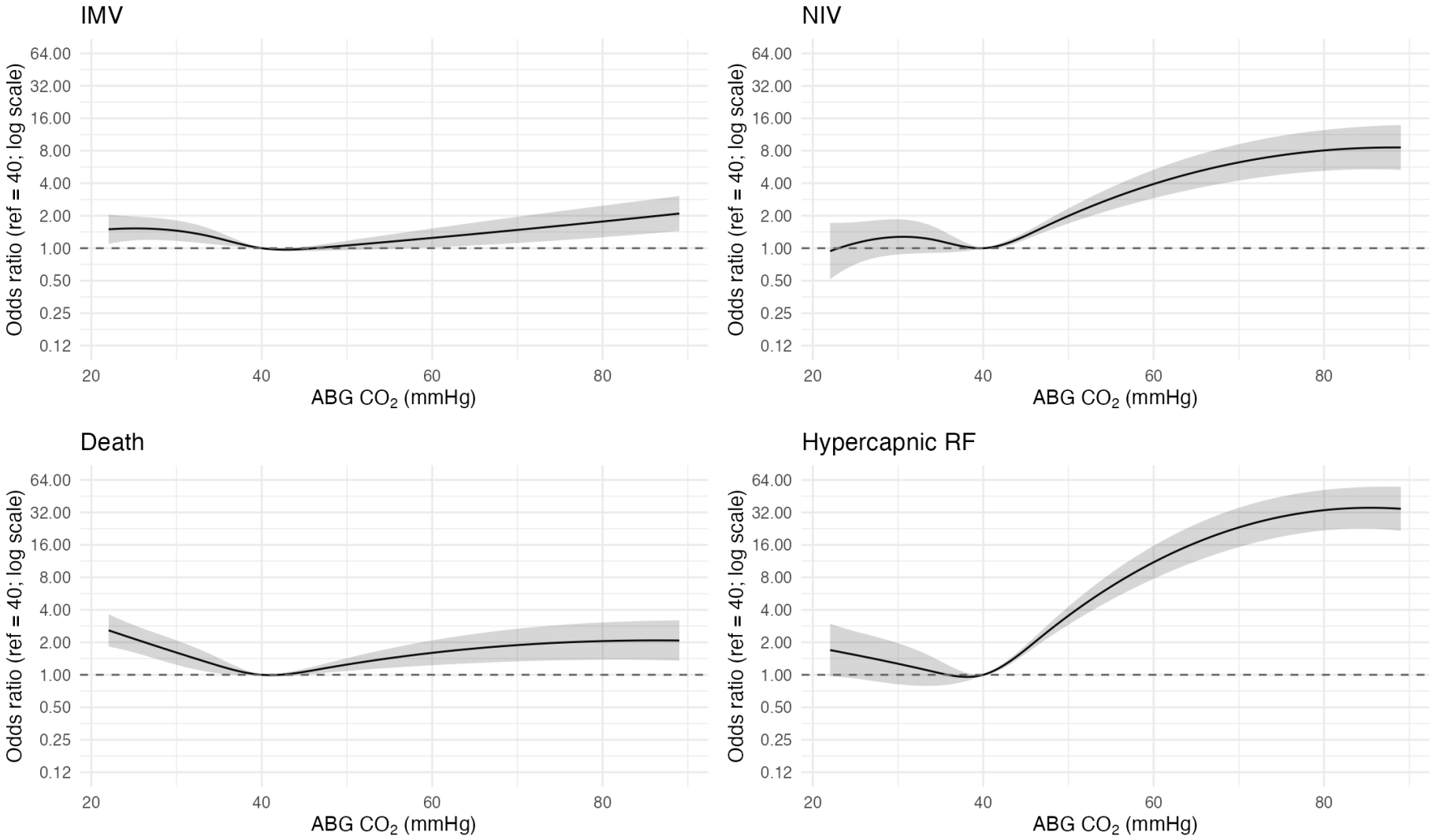
VBG uses the same GBM tuning as ABG (shared `gbm_params`).

2.0.4 5.4 VBG IPW weighting and spline models

Propensity-weighted adjusted odds ratios by VBG CO2 (ref = 45; conditional on X)



Reference VBG CO2 = 45 mmHg



2.0.5 5.5 Three-level PCO2 categories (weighted; ABG, VBG)

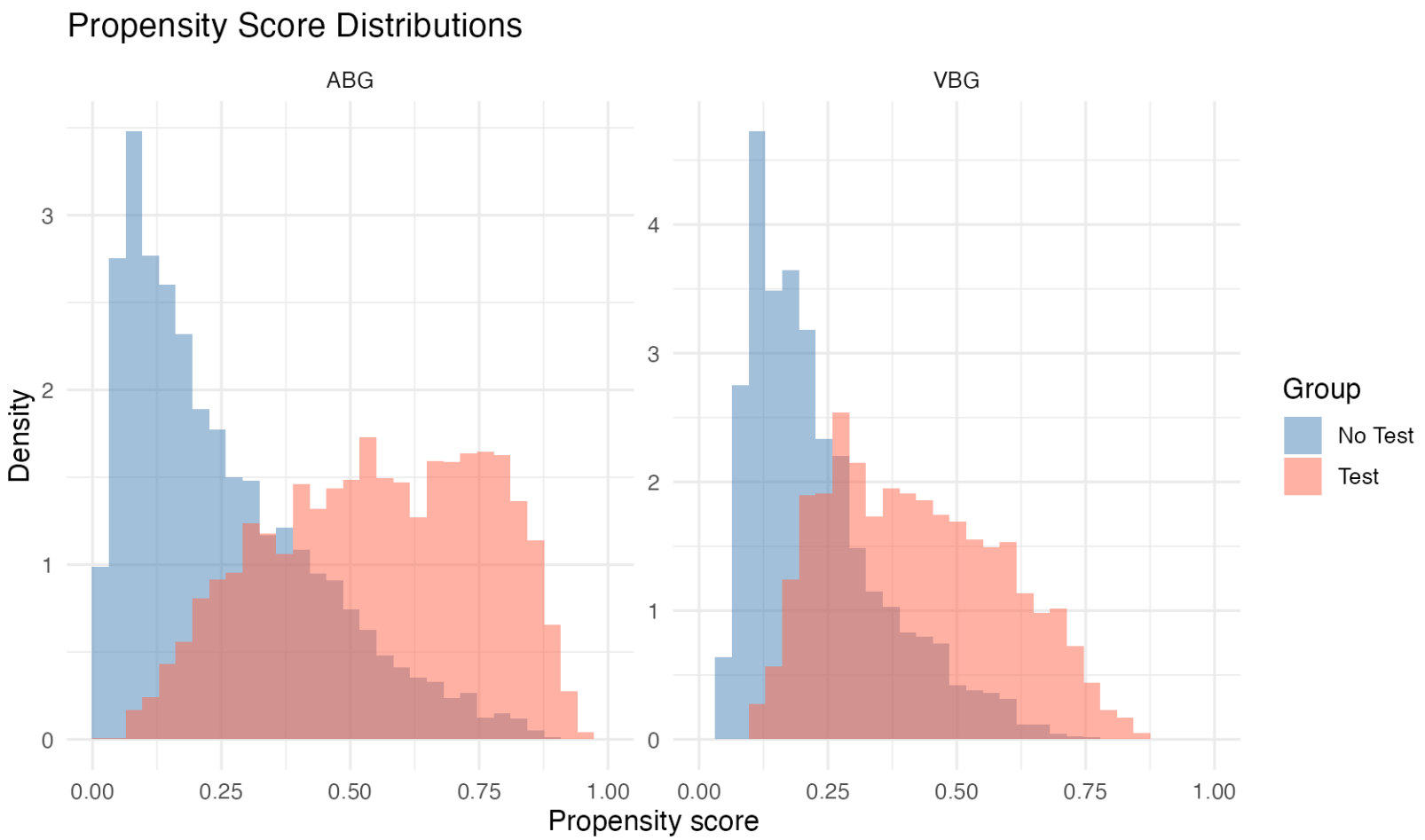
Three groups with weights and covariate adjustment

2.0.6 5.6 Three-level PCO2 categories (weighted; ABG vs VBG only)

Three groups with weights and covariate adjustment: ABG and VBG

2.1 6) Propensity score diagnostics

Plotting propensity scores



3 Multiple Imputation Analysis

added 12/6/2025

Pre-imputation missingness

Variable	Missing (n)	Missing (%)
vbg_o2sat	8,942	86.8%
bnp	8,441	81.9%
vbg_co2	7,369	71.5%
spo2	7,297	70.8%
paco2	6,595	64.0%
serum_lac	6,272	60.9%
curr_bmi	5,837	56.7%
serum_phos	5,522	53.6%
temp_new	4,975	48.3%
hr	3,719	36.1%
dbp	3,072	29.8%
sbp	3,042	29.5%
wbc	1,828	17.7%
serum_ca	1,031	10.0%
serum_cr	955	9.3%
plt	799	7.8%
serum_k	792	7.7%
serum_cl	590	5.7%
serum_hco3	569	5.5%
sodium	513	5.0%
age_at_encounter	0	0.0%
sex	0	0.0%
race_ethnicity	0	0.0%
copd	0	0.0%
asthma	0	0.0%
osa	0	0.0%
chf	0	0.0%
acute_nmd	0	0.0%
phtn	0	0.0%
ckd	0	0.0%
dm	0	0.0%
location	0	0.0%
encounter_type	0	0.0%
has_abg	0	0.0%
has_vbg	0	0.0%
imv_proc	0	0.0%

3.1 7) Packages and reproducibility

3.1.1 7.2 Missingness structure and drivers

`Missingness by key strata (pre-imputation; top 10 variables; full table saved to /Users/reblocke/Research/abg-vbg-project/Results/missingness-by-strata.csv).`

3.1.2 7.3 Monte Carlo error check after MI

3.2 8) Pre-imputation data prep (consistent types & predictors)

Why: MI models need coherent types; using exactly the same covariates as the propensity score models avoids model drift.

3.3 9) Imputation model specification (MICE)

3.3.1 9.1 Predictor matrix & methods. Run MICE (moderate settings for scale)

MC error diagnostic model: Diagnostic model: imv_proc ~ has_abg + age_at_encounter + curr_bmi + sex + encounter_type (unweighted).

3.3.2 9.2 Convergence & plausibility checks

3.3.3 9.3 Observed vs imputed distributions (by strata)

3.3.4 9.2 Missingness audit (what, where, how much)

3.4 10) Refit propensity models within each imputation

GBM recipe matches the non-MI run (shared `gbm_params`, balance-based stopping).

Note: the MI computations below run in a single pass per imputation (weights, balance, cat3, spline). Subsequent MI sections reuse those outputs and will stop if they are missing.

3.4.1 FAIL-FAST CHECKS

3.4.2 10.1 ABG propensity (has_abg)

Table 8: ABG weight diagnostics (MI; median across imputations)

n	min	p99.99%	max	ess
3708	0.435	3.138	3.141	3010.553

3.4.3 10.2 Balance diagnostics across imputations

Table 9: ABG: worst target SMD rows across imputations (top 10)

variable	level	type	smd_pre	smd_post	group	imp	abs_post
encounter_type	Emergency	factor	-0.3731634	-0.1638587	ABG	49	0.1638587
encounter_type	Inpatient	factor	0.3731634	0.1638587	ABG	49	0.1638587
encounter_type	Inpatient	factor	0.3731634	0.1634623	ABG	14	0.1634623
encounter_type	Emergency	factor	-0.3731634	-0.1634623	ABG	14	0.1634623
encounter_type	Emergency	factor	-0.3731634	-0.1626141	ABG	31	0.1626141
encounter_type	Inpatient	factor	0.3731634	0.1626141	ABG	31	0.1626141
encounter_type	Inpatient	factor	0.3731634	0.1626009	ABG	34	0.1626009
encounter_type	Emergency	factor	-0.3731634	-0.1626009	ABG	34	0.1626009
encounter_type	Inpatient	factor	0.3731634	0.1625328	ABG	33	0.1625328
encounter_type	Emergency	factor	-0.3731634	-0.1625328	ABG	33	0.1625328

Table 10: ABG: max |Target SMD| summary across imputations

med	p90	max
0.1565851	0.1606144	0.1638587

3.4.4 10.3 VBG propensity (has_vbg)

Table 11: VBG weight diagnostics (MI; median across imputations)

n	min	p99.99%	max	ess
2934	0.347	2.937	2.939	2219.903

3.4.5 10.4 VBG balance

Table 12: VBG: worst target SMD rows across imputations (top 10)

variable	level	type	smd_pre	smd_post	group	imp	abs_post
curr_bmi	NA	numeric	-0.2376844	-0.0824508	VBG	12	0.0824508
curr_bmi	NA	numeric	-0.2101529	-0.0769167	VBG	79	0.0769167
curr_bmi	NA	numeric	-0.2126298	-0.0767876	VBG	30	0.0767876
curr_bmi	NA	numeric	-0.2021219	-0.0732630	VBG	15	0.0732630
curr_bmi	NA	numeric	-0.2198407	-0.0729904	VBG	26	0.0729904
curr_bmi	NA	numeric	-0.2045047	-0.0729658	VBG	34	0.0729658
curr_bmi	NA	numeric	-0.2225464	-0.0720591	VBG	42	0.0720591
curr_bmi	NA	numeric	-0.2066772	-0.0717978	VBG	27	0.0717978
curr_bmi	NA	numeric	-0.2118519	-0.0713313	VBG	13	0.0713313
curr_bmi	NA	numeric	-0.2379866	-0.0708582	VBG	20	0.0708582

Table 13: VBG: max |Target SMD| summary across imputations

med	p90	max
0.0596963	0.071378	0.0824508

3.5 11) Weighted outcome models within each imputation + pooling

Within each imputation, fit covariate-adjusted CO2 spline outcome models **only in the measured cohort** (has_abg==1 for PaCO2; has_vbg==1 for VBG CO2), using IPSW weights to address nonrandom testing. Curves are pooled pointwise across imputations (Rubin's rules on the log-OR scale) and displayed as odds ratios relative to CO2_ref at a reference covariate profile.

3.5.1 11.1 Helper: fit + extract log-OR and SE from svyglm

3.5.2 11.3 VBG: MI pooled spline models (treated cohort only)

3.6 12) Explainability on one representative imputation

To manage runtime, compute SHAP summaries (importance + dependence) on the first imputed dataset and its fitted GBM(s).

3.7 13) MI three-level PCO2 helpers and checks

3.8 14) MI + IPW three-level PCO2 (ABG & VBG)

3.8.1 14.1 ABG: MI + IPW, three-level PCO2 outcomes

3.8.2 14.2 VBG: MI + IPW, three-level PCO2 outcomes

3.8.3 14.3 Table 3: MI-pooled IPW associations (3-level CO)

3.8.4 14.4 Summary: adjusted CO2-category associations across analysis tracks

Table 14: Adjusted odds ratios (low/high vs normal) across analysis tracks; n/events reflect model sample size (median across imputations for MI).

method	group	outcome_label	n_model	events	Low vs normal	High vs normal
Unweighted adjusted	ABG	IMV	3708	937	1.39 (1.16, 1.67)	1.19 (0.99, 1.43)
Unweighted adjusted	ABG	NIV	3708	360	0.99 (0.73, 1.34)	2.60 (2.01, 3.36)
Unweighted adjusted	ABG	Death (60d)	3708	635	1.58 (1.28, 1.96)	1.30 (1.05, 1.61)
Unweighted adjusted	ABG	Hypercapnic RF	3708	395	1.47 (1.02, 2.11)	8.41 (6.37, 11.26)
Unweighted adjusted	VBG	IMV	2934	452	1.11 (0.86, 1.44)	1.51 (1.18, 1.94)
Unweighted adjusted	VBG	NIV	2934	219	0.98 (0.65, 1.45)	2.77 (1.99, 3.89)
Unweighted adjusted	VBG	Death (60d)	2934	396	1.71 (1.31, 2.23)	1.30 (0.99, 1.70)
Unweighted adjusted	VBG	Hypercapnic RF	2934	271	0.69 (0.42, 1.10)	7.42 (5.39, 10.37)
IPW adjusted	ABG	IMV	3708	937	1.35 (1.10, 1.65)	1.15 (0.93, 1.41)
IPW adjusted	ABG	NIV	3708	360	1.14 (0.80, 1.62)	2.84 (2.14, 3.76)
IPW adjusted	ABG	Death (60d)	3708	635	1.47 (1.15, 1.88)	1.28 (1.01, 1.64)

method	group	outcome_label	n_model	events	Low vs normal	High vs normal
IPW adjusted	ABG	Hypercapnic RF	3708	395	1.65 (1.09, 2.52)	9.08 (6.57, 12.57)
IPW adjusted	VBG	IMV	2934	452	1.13 (0.85, 1.51)	1.40 (1.06, 1.84)
IPW adjusted	VBG	NIV	2934	219	0.93 (0.60, 1.44)	3.09 (2.15, 4.44)
IPW adjusted	VBG	Death (60d)	2934	396	1.74 (1.30, 2.32)	1.42 (1.05, 1.91)
IPW adjusted	VBG	Hypercapnic RF	2934	271	0.62 (0.36, 1.05)	8.35 (5.82, 11.98)
IPW + MI adjusted	ABG	IMV	3708	937	1.36 (1.11, 1.66)	1.17 (0.96, 1.43)
IPW + MI adjusted	ABG	NIV	3708	360	1.02 (0.73, 1.45)	2.74 (2.06, 3.63)
IPW + MI adjusted	ABG	Death (60d)	3708	635	1.46 (1.15, 1.86)	1.25 (0.99, 1.58)
IPW + MI adjusted	ABG	Hypercapnic RF	3708	395	1.57 (1.06, 2.33)	9.24 (6.77, 12.61)
IPW + MI adjusted	VBG	IMV	2934	452	1.14 (0.84, 1.54)	1.45 (1.09, 1.94)
IPW + MI adjusted	VBG	NIV	2934	219	0.91 (0.57, 1.44)	2.90 (1.99, 4.24)
IPW + MI adjusted	VBG	Death (60d)	2934	396	1.62 (1.19, 2.20)	1.23 (0.90, 1.67)
IPW + MI adjusted	VBG	Hypercapnic RF	2934	271	0.59 (0.33, 1.05)	7.30 (4.96, 10.76)

3.9 Manuscript outputs summary

Table 15: Cohort flow summary

metric	n
Full cohort (raw)	833476
Analytic subset	10303
ABG tested	3708
ABG with PaCO2	3708
VBG tested	2934
VBG with VBG CO2	2934

Table 16: Outcome counts by cohort (ABG/VBG tested)

outcome	group	n	events
IMV	ABG	3708	937
NIV	ABG	3708	360

outcome	group	n	events
Death (60d)	ABG	3708	635
Hypercapnic RF	ABG	3708	395
IMV	VBG	2934	452
NIV	VBG	2934	219
Death (60d)	VBG	2934	396
Hypercapnic RF	VBG	2934	271

Table 17: Weighting diagnostics summary (non-MI)

	n	mean	sd	min	p01	p05	p95	p99	max	sum_w	ess	top01_weight	ps_flag	trunc_rate	ps_min	ps_p01	ps_p05	ps_p95	ps_max	group
1%…	13708	1	0.597986	0.164772	0.248968	0.351746	0.920743	0.957284	2.373093	3708	2731.50	0.090372288	0.119212	0.010248	0.102875	0.119212	0.201489	0.859516	0.956974	ABG
1%…	22934	1	0.472999	0.140588	0.144317	0.249188	0.896535	0.926928	2.669643	2934	2397.73	0.090266518	0.130406	0.010224	0.101268	0.130406	0.178916	0.714863	0.866347	VBG

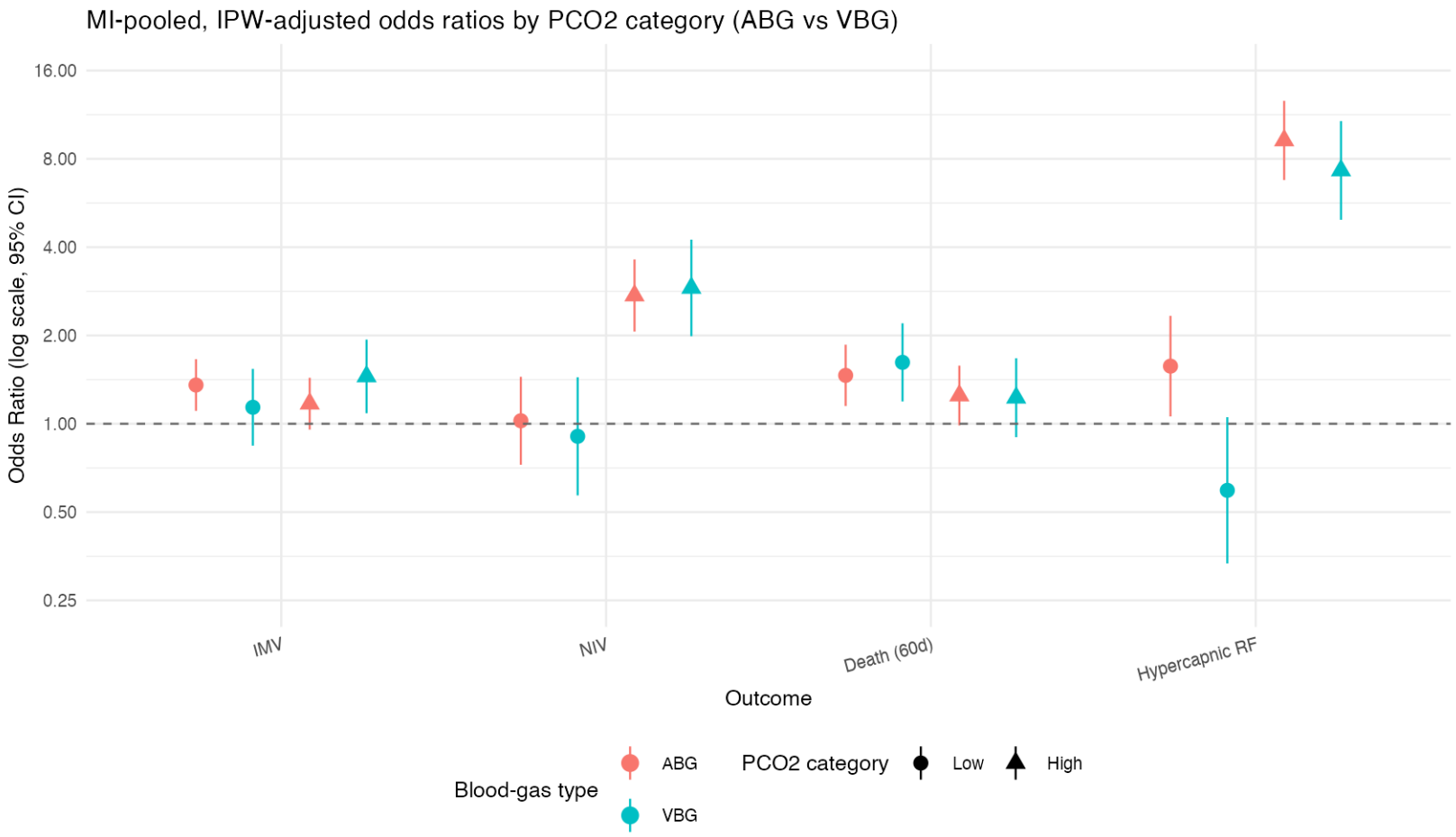
Table 18: Top 10 variables by missingness (pre-imputation)

variable	pct_missing
vbg_co2	71.52286
paco2	64.01048
serum_lac	60.87547
curr_bmi	56.65340
serum_phos	53.59604
temp_new	48.28691
hr	36.09628
dbp	29.81656
sbp	29.52538
wbc	17.74241

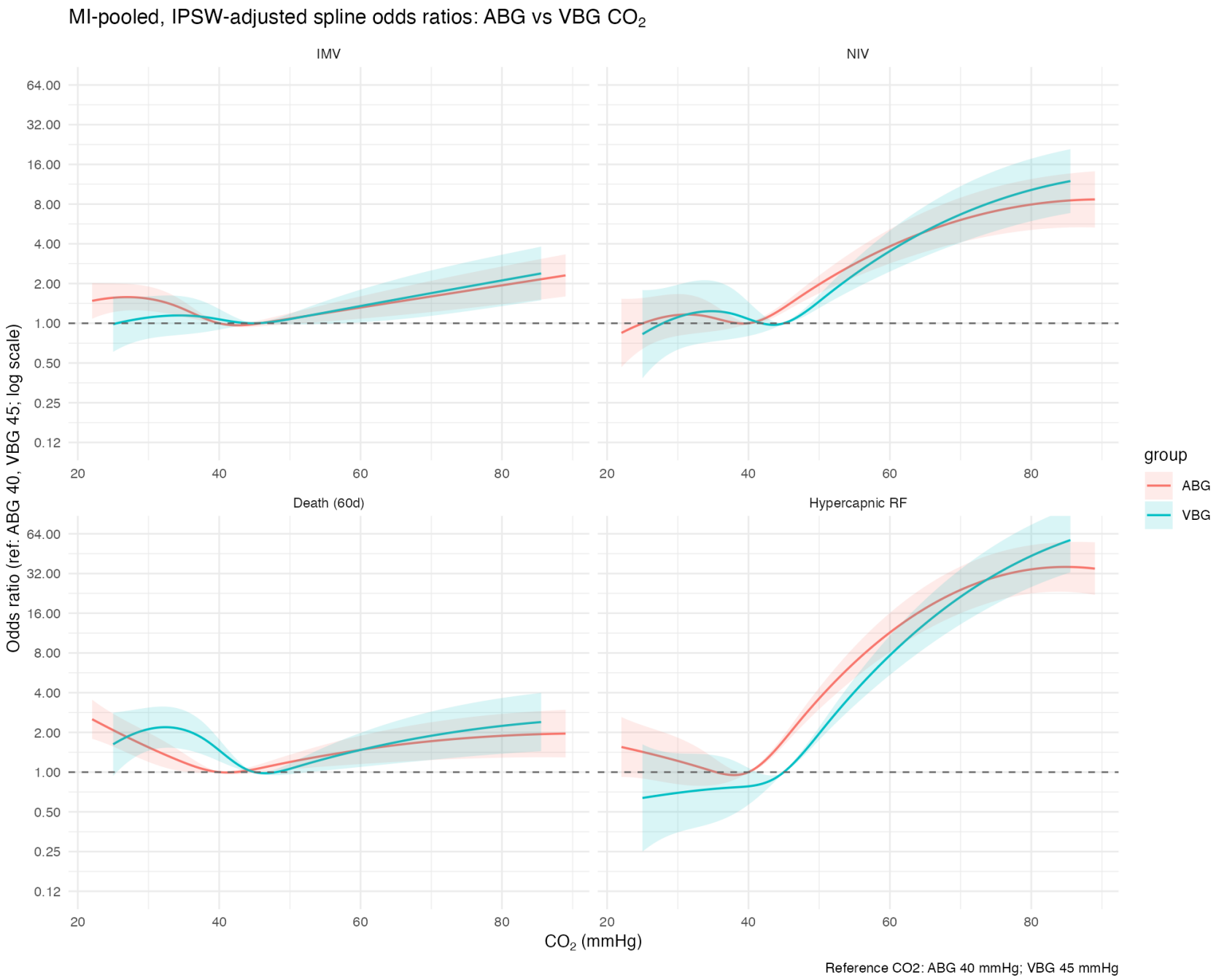
Table 19: MI specification (methods used)

m	maxit	methods
80	20	pmm

3.9.1 14.3 Visualization: pooled three-level ORs



3.9.2 15.3 Visualization



3.10 Diagnostics

3.10.1 Diagnostics inputs and settings

3.10.2 Missingness diagnostics

3.10.3 MI convergence and mixing

3.10.4 MI stability across m

3.10.5 MI maxit sensitivity (sampled)

3.10.6 Propensity and weight diagnostics

3.10.7 Balance diagnostics

Table 20: Target balance (top 10 by max |SMD|)

group	variable	max_abs_pre	max_abs_post
ABG	encounter_type	0.3731634	0.1919700
ABG	curr_bmi	0.2718821	0.1851747
ABG	location	0.1841839	0.1093023
ABG	chf	0.0815995	0.0788821
ABG	serum_ca	0.2281003	0.0788256
ABG	age_at_encounter	0.1087789	0.0783849
ABG	sbp	0.1868308	0.0750944
ABG	dbp	0.1744865	0.0717674
ABG	copd	0.0796943	0.0696323
ABG	wbc	0.1054266	0.0545592
VBG	location	0.3928212	0.1623070
VBG	curr_bmi	0.2555025	0.1619552
VBG	serum_cl	0.1545760	0.0962703
VBG	race_ethnicity	0.1968390	0.0892528
VBG	hr	0.1431343	0.0887112
VBG	dbp	0.1220568	0.0731679
VBG	sbp	0.1560808	0.0728967

group	variable	max_abs_pre	max_abs_post
VBG	dm	0.0666617	0.0646280
VBG	ckd	0.0738042	0.0595942
VBG	serum_cr	0.0998610	0.0490036

Table 21: Worst target SMD rows across imputations (top 10)

variable	level	type	smd_pre	smd_post	group	imp	abs_post
encounter_type	Emergency	factor	-0.3731634	-0.1638587	ABG	49	0.1638587
encounter_type	Inpatient	factor	0.3731634	0.1638587	ABG	49	0.1638587
encounter_type	Inpatient	factor	0.3731634	0.1634623	ABG	14	0.1634623
encounter_type	Emergency	factor	-0.3731634	-0.1634623	ABG	14	0.1634623
encounter_type	Emergency	factor	-0.3731634	-0.1626141	ABG	31	0.1626141
encounter_type	Inpatient	factor	0.3731634	0.1626141	ABG	31	0.1626141
encounter_type	Inpatient	factor	0.3731634	0.1626009	ABG	34	0.1626009
encounter_type	Emergency	factor	-0.3731634	-0.1626009	ABG	34	0.1626009
encounter_type	Inpatient	factor	0.3731634	0.1625328	ABG	33	0.1625328
encounter_type	Emergency	factor	-0.3731634	-0.1625328	ABG	33	0.1625328
curr_bmi	NA	numeric	-0.2376844	-0.0824508	VBG	12	0.0824508
curr_bmi	NA	numeric	-0.2101529	-0.0769167	VBG	79	0.0769167
curr_bmi	NA	numeric	-0.2126298	-0.0767876	VBG	30	0.0767876
curr_bmi	NA	numeric	-0.2021219	-0.0732630	VBG	15	0.0732630
curr_bmi	NA	numeric	-0.2198407	-0.0729904	VBG	26	0.0729904
curr_bmi	NA	numeric	-0.2045047	-0.0729658	VBG	34	0.0729658
curr_bmi	NA	numeric	-0.2225464	-0.0720591	VBG	42	0.0720591
curr_bmi	NA	numeric	-0.2066772	-0.0717978	VBG	27	0.0717978
curr_bmi	NA	numeric	-0.2118519	-0.0713313	VBG	13	0.0713313
curr_bmi	NA	numeric	-0.2379866	-0.0708582	VBG	20	0.0708582

Table 22: Distribution of max |Target SMD| across imputations

group	med	iqr	max
ABG	0.1565851	0.0046927	0.1638587

group	med	iqr	max
VBG	0.0596963	0.0087136	0.0824508

Table 23: Most frequent worst-balance terms (top 10 per group)

group	term	n
ABG	curr_bmi	80
ABG	encounter_type:Emergency	80
ABG	encounter_type:Inpatient	80
ABG	location:0	80
ABG	location:1	80
ABG	serum_ca	79
ABG	sbp	68
ABG	age_at_encounter	60
ABG	chf:0	59
ABG	chf:1	53
VBG	curr_bmi	80
VBG	location:1	80
VBG	race_ethnicity:1	78
VBG	location:3	76
VBG	asthma:1	67
VBG	asthma:0	65
VBG	race_ethnicity:0	63
VBG	serum_ca	60
VBG	serum_cl	55
VBG	encounter_type:Emergency	46

3.10.8 Outcome diagnostics

3.10.9 Diagnostics summary and audit

Table 24: Diagnostics summary (IPSW + MI)

block	run_mode	m	maxit	pilot_frac	stop_method	ps_floor	[illegible] (ps_floor_quantile, weight_p01, weight_p05, weight_p95, weight_p99, weight_max, top1_weight_share, ratio)	Median over imputations of max |Target SMD|	Max over imputations of max |Target SMD|	runtime_total_hrs	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ABG-weights	pilot	80	20	0.02	smd.max	0.01	[illegible]	[illegible]	0.1638587	26.17883	16	16	16	0	0
VBG-weights	pilot	80	20	0.02	smd.max	0.01	[illegible]	[illegible]	0.0824508	26.17883	16	16	16	0	0
ABG-outcomes	pilot	80	20	0.02	smd.max	0.01	[illegible]	[illegible]	0.1638587	26.17883	16	16	16	0	0
VBG-outcomes	pilot	80	20	0.02	smd.max	0.01	[illegible]	[illegible]	0.0824508	26.17883	16	16	16	0	0

3.10.10 Performance / runtime log

Table 25: Worst fitted-probability extremes (top 10)

stage	component	analysis_variant	model_type	group	outcome	imputation	n_used	events	converged	iter	sep_flag	nonconv_flag	min_phat	max_phat	warning_n	top_warning	error_message	extreme
outcome	spline	mi_ipw	spline	ABG	hypercap_resp_failure	22	3708	395	TRUE	12	TRUE	FALSE	0	0.7486054	0	NA	NA	0
outcome	spline	mi_ipw	spline	ABG	hypercap_resp_failure	68	3708	395	TRUE	12	TRUE	FALSE	0	0.7348681	0	NA	NA	0

stage	component	analysis_variant	model_type	group	outcome	imputation	n_used	events	converged	iter	sep_flag	conv_flag	min_phat	max_phat	warning_n	top_warning	error_message	extreme
outcome	spline	mi_ipw	spline	ABG	hypercap_resp_failure	9	3708	395	TRUE	13	TRUE	FALSE	0	0.7368799	0	NA	NA	0
outcome	spline	mi_ipw	spline	ABG	hypercap_resp_failure	69	3708	395	TRUE	12	TRUE	FALSE	0	0.7356951	0	NA	NA	0
outcome	spline	mi_ipw	spline	ABG	hypercap_resp_failure	51	3708	395	TRUE	13	TRUE	FALSE	0	0.7326796	0	NA	NA	0
outcome	spline	mi_ipw	spline	ABG	hypercap_resp_failure	14	3708	395	TRUE	12	TRUE	FALSE	0	0.7400813	0	NA	NA	0
outcome	spline	mi_ipw	spline	ABG	hypercap_resp_failure	64	3708	395	TRUE	13	TRUE	FALSE	0	0.7450553	0	NA	NA	0
outcome	spline	mi_ipw	spline	ABG	hypercap_resp_failure	49	3708	395	TRUE	13	TRUE	FALSE	0	0.7320209	0	NA	NA	0
outcome	spline	mi_ipw	spline	ABG	hypercap_resp_failure	31	3708	395	TRUE	13	TRUE	FALSE	0	0.7552948	0	NA	NA	0
outcome	spline	mi_ipw	spline	ABG	hypercap_resp_failure	67	3708	395	TRUE	13	TRUE	FALSE	0	0.7413213	0	NA	NA	0

Table 26: Top MICE loggedEvents drivers

variable	n	pct	empty	run_id	run_ts
NA	NA	NA	TRUE	20260129_163529	2026-01-29 16:35:29.236332

3.10.11 Performance / runtime log

Table 27: Top runtime steps (seconds)

step_name	seconds	start_time	end_time	notes	run_id	run_mode	n_subset
mi_single_pass	1884.875999	2026-01-29 16:46:08.539797	2026-01-29 17:17:33.415796	m=80	20260129_163529	pilot	10303
shap_summary	42.090738	2026-01-29 17:17:33.755157	2026-01-29 17:18:15.845895	frac_rows=0.03; nsim=8	20260129_163529	pilot	10303
mice_batch_40	10.334954	2026-01-29 16:45:27.490115	2026-01-29 16:45:37.825069	batch=40; m=2; maxit=20	20260129_163529	pilot	10303
mice_batch_24	9.938268	2026-01-29 16:42:35.887517	2026-01-29 16:42:45.825785	batch=24; m=2; maxit=20	20260129_163529	pilot	10303
mice_batch_20	9.928984	2026-01-29 16:41:52.005054	2026-01-29 16:42:01.934038	batch=20; m=2; maxit=20	20260129_163529	pilot	10303
mice_batch_21	9.917904	2026-01-29 16:42:03.421551	2026-01-29 16:42:13.339455	batch=21; m=2; maxit=20	20260129_163529	pilot	10303
mice_batch_25	9.802304	2026-01-29 16:42:47.360336	2026-01-29 16:42:57.16264	batch=25; m=2; maxit=20	20260129_163529	pilot	10303
mice_batch_36	9.777425	2026-01-29 16:44:43.742995	2026-01-29 16:44:53.52042	batch=36; m=2; maxit=20	20260129_163529	pilot	10303
mice_batch_18	9.711698	2026-01-29 16:41:30.201736	2026-01-29 16:41:39.913434	batch=18; m=2; maxit=20	20260129_163529	pilot	10303
mice_batch_14	9.692061	2026-01-29 16:40:46.96076	2026-01-29 16:40:56.652821	batch=14; m=2; maxit=20	20260129_163529	pilot	10303
mice_batch_6	9.518577	2026-01-29 16:39:23.019922	2026-01-29 16:39:32.538499	batch=6; m=2; maxit=20	20260129_163529	pilot	10303
mice_batch_39	9.494741	2026-01-29 16:45:16.477868	2026-01-29 16:45:25.972609	batch=39; m=2; maxit=20	20260129_163529	pilot	10303
mice_batch_38	9.489321	2026-01-29 16:45:05.690388	2026-01-29 16:45:15.179709	batch=38; m=2; maxit=20	20260129_163529	pilot	10303
mice_batch_23	9.446071	2026-01-29 16:42:25.142269	2026-01-29 16:42:34.58834	batch=23; m=2; maxit=20	20260129_163529	pilot	10303
mice_batch_35	9.444244	2026-01-29 16:44:32.856629	2026-01-29 16:44:42.300873	batch=35; m=2; maxit=20	20260129_163529	pilot	10303

Table 28: Runtime summary (total + top 5 steps)

step_name	seconds
TOTAL	2302.026344
mi_single_pass	1884.875999
shap_summary	42.090738
mice_batch_40	10.334954
mice_batch_24	9.938268
mice_batch_20	9.928984

3.11 16) Save, export, and session info

Table 29: Diagnostics audit: top issues (see Results/diagnostics_audit.md for full details)

severity	component	evidence_file	evidence_snippet	why_it_matters	recommended_fix
high	Balance	Results/balance_target_imp_summary.csv	ABG max|SMD|=0.164	ABG target balance exceeds 0.10 threshold across imputations.	Revisit GBM tuning, covariate set, or truncation to improve ABG balance.
high	Outcome	Results/model_fit_diagnostics.csv	sep_flag TRUE for 1076 / 1332 fits	High rate of separation/near-separation can bias ORs and CIs.	Inspect flagged outcomes; consider penalized fits or check data sparsity.

Software: R 4.5.2 ; key packages: mice, WeightIt, cobalt, survey, rms.

Variable	Stratum	Level	% missing in level	% missing overall
0	vbg_o2sat	86.6	has_abg	86.8
1	vbg_o2sat	87.1	has_abg	86.8
0	vbg_o2sat	99.3	has_vbg	86.8
1	vbg_o2sat	55.4	has_vbg	86.8
0	vbg_o2sat	87.3	imv_proc	86.8
1	vbg_o2sat	82.8	imv_proc	86.8
0	bnp	84.2	has_abg	81.9
1	bnp	77.9	has_abg	81.9
0	bnp	82.8	has_vbg	81.9
1	bnp	79.8	has_vbg	81.9
0	bnp	82.3	imv_proc	81.9
1	bnp	78.6	imv_proc	81.9
0	vbg_co2	71.7	has_abg	71.5
1	vbg_co2	71.2	has_abg	71.5
0	vbg_co2	100.0	has_vbg	71.5
1	vbg_co2	0.0	has_vbg	71.5
0	vbg_co2	72.9	imv_proc	71.5
1	vbg_co2	60.5	imv_proc	71.5
0	spo2	69.7	has_abg	70.8
1	spo2	72.7	has_abg	70.8
0	spo2	71.8	has_vbg	70.8
1	spo2	68.4	has_vbg	70.8
0	spo2	71.4	imv_proc	70.8
1	spo2	66.6	imv_proc	70.8
0	paco2	100.0	has_abg	64.0
1	paco2	0.0	has_abg	64.0
0	paco2	64.2	has_vbg	64.0
1	paco2	63.6	has_vbg	64.0
0	paco2	69.7	imv_proc	64.0
1	paco2	18.0	imv_proc	64.0
0	serum_lac	72.4	has_abg	60.9
1	serum_lac	40.4	has_abg	60.9
0	serum_lac	65.4	has_vbg	60.9
1	serum_lac	49.5	has_vbg	60.9
0	serum_lac	64.2	imv_proc	60.9
1	serum_lac	33.9	imv_proc	60.9
0	curr_bmi	55.9	has_abg	56.7
1	curr_bmi	58.1	has_abg	56.7
0	curr_bmi	52.2	has_vbg	56.7
1	curr_bmi	67.9	has_vbg	56.7
0	curr_bmi	55.4	imv_proc	56.7
1	curr_bmi	66.5	imv_proc	56.7
0	serum_phos	65.0	has_abg	53.6
1	serum_phos	33.3	has_abg	53.6
0	serum_phos	58.8	has_vbg	53.6
1	serum_phos	40.6	has_vbg	53.6
0	serum_phos	57.6	imv_proc	53.6
1	serum_phos	21.4	imv_proc	53.6
0	temp_new	52.3	has_abg	48.3

Table 7: Predictors of missingness (logit OR; top 50 by p-value; full table saved to /Users/reblocke/Research/abg-vbg-project/Results/missingness-drivers.csv).

Target	Predictor	OR	LCL	UCL	p
temp_new	location3	21.40	17.60	26.03	0e+00
serum_phos	encounter_typeInpatient	0.13	0.11	0.15	0e+00
temp_new	location1	17.77	14.12	22.35	0e+00
hr	location1	12.66	10.10	15.87	0e+00
sbp	encounter_typeInpatient	0.04	0.03	0.06	0e+00
dbp	encounter_typeInpatient	0.04	0.03	0.06	0e+00
serum_lac	has_abg	0.24	0.20	0.28	0e+00
vbg_o2sat	has_vbg	0.00	0.00	0.00	0e+00
dbp	location3	1564.39	568.19	4307.18	0e+00
serum_lac	location3	3.25	2.72	3.89	0e+00
serum_phos	has_abg	0.34	0.29	0.41	0e+00
wbc	location3	3.77	3.01	4.73	0e+00
sbp	location3	3235.23	789.52	13257.00	0e+00
hr	location2	3.80	2.92	4.95	0e+00
serum_phos	has_vbg	0.37	0.30	0.45	0e+00
serum_hco3	age_at_encounter	0.96	0.96	0.97	0e+00
temp_new	location2	3.33	2.55	4.35	0e+00
serum_cl	age_at_encounter	0.97	0.96	0.97	0e+00
serum_ca	age_at_encounter	0.97	0.96	0.98	0e+00
sodium	age_at_encounter	0.97	0.96	0.97	0e+00
vbg_o2sat	location3	19.43	9.93	38.01	0e+00
serum_cr	age_at_encounter	0.97	0.96	0.97	0e+00
temp_new	has_abg	0.47	0.39	0.56	0e+00
wbc	location1	3.19	2.43	4.20	0e+00
serum_k	age_at_encounter	0.97	0.96	0.98	0e+00
serum_phos	location3	0.49	0.41	0.59	0e+00
wbc	location2	3.37	2.45	4.63	0e+00
temp_new	encounter_typeInpatient	0.55	0.47	0.65	0e+00
serum_ca	has_abg	0.20	0.13	0.31	0e+00
serum_k	has_abg	0.15	0.09	0.26	0e+00
hr	has_abg	0.50	0.41	0.61	0e+00
serum_hco3	has_abg	0.16	0.09	0.27	0e+00
vbg_o2sat	encounter_typeInpatient	0.28	0.19	0.40	0e+00
sodium	has_abg	0.14	0.08	0.25	0e+00
plt	age_at_encounter	0.98	0.97	0.98	0e+00
serum_cl	has_abg	0.18	0.11	0.30	0e+00
serum_cr	has_abg	0.24	0.15	0.37	0e+00
plt	has_abg	0.20	0.12	0.33	0e+00
vbg_o2sat	location2	0.08	0.04	0.17	0e+00
wbc	age_at_encounter	0.98	0.98	0.99	0e+00
serum_lac	has_vbg	0.56	0.46	0.67	0e+00
serum_phos	imv_proc	0.39	0.29	0.52	0e+00
wbc	has_vbg	0.48	0.38	0.62	0e+00
plt	has_vbg	0.16	0.09	0.30	0e+00
serum_hco3	has_vbg	0.14	0.07	0.27	0e+00

Monte Carlo error vs SE (diagnostic only)

Term	Estimate	SE	MC error	MC error / SE	2.5%	97.5%
(Intercept)	-3.651	0.309	0.024	0.077	-4.258517535	-3.0426399834
has_abg	2.099	0.083	0.001	0.016	1.936507587	2.2624632033
age_at_encounter	-0.005	0.002	0.000	0.014	-0.008564536	-0.0006643529
curr_bmi	-0.013	0.008	0.001	0.089	-0.027716041	0.0024779632
sexMale	0.161	0.069	0.001	0.015	0.025811998	0.2958823723
encounter_typeInpatient	1.158	0.111	0.001	0.008	0.940408548	1.3754341651

Table 3. MI-pooled IPW associations between CO category and outcomes (adjusted)

Cohort	Outcome	Low vs normal OR (95% CI)	High vs normal OR (95% CI)
ABG	IMV	1.36 (1.11, 1.66)	1.17 (0.96, 1.43)
ABG	NIV	1.02 (0.73, 1.45)	2.74 (2.06, 3.63)
ABG	Death (60d)	1.46 (1.15, 1.86)	1.25 (0.99, 1.58)
ABG	Hypercapnic RF	1.57 (1.06, 2.33)	9.24 (6.77, 12.61)
VBG	IMV	1.14 (0.84, 1.54)	1.45 (1.09, 1.94)
VBG	NIV	0.91 (0.57, 1.44)	2.90 (1.99, 4.24)
VBG	Death (60d)	1.62 (1.19, 2.20)	1.23 (0.90, 1.67)
VBG	Hypercapnic RF	0.59 (0.33, 1.05)	7.30 (4.96, 10.76)

Weighted survey GLMs adjusted for baseline covariates; weights = MI-specific GBM IPW; m = 80 imputations (seed 20251206); reference = Normal.