

Handout for
Blood Pressure and Cardiovascular Disease:
A Reevaluation of Their Relationship Using Multiple Spline Regression *

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Graduate Student Outreach Seminar
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Disposition of Framingham Study Patient Visits

	Age			Total
	45-54	55-64	65-74	
Male	7,231	8,321	4,517	20,069
Female	9,048	10,781	6,471	26,300
Total	16,279	19,102	10,988	46,369

SBP Deciles

	Age	Min	10%	20%	30%	40%	Median
Male	45-54	80.1	110.2	117.8	120.2	126.0	130.1
	55-64	80.1	113.8	120.0	125.9	130.1	135.8
	65-74	79.9	116.0	123.9	129.9	134.2	139.9
Female	45-54	82.1	109.8	114.8	120.0	124.2	130.0
	55-64	73.9	112.2	120.1	127.8	132.0	138.1
	65-74	85.8	119.8	128.1	133.9	139.9	145.2
	Age	60%	70%	80%	90%	Max	
Male	45-54	135.2	140.2	148.1	159.9	240.0	
	55-64	140.1	147.8	155.9	169.8	275.9	
	65-74	144.2	150.1	159.9	170.1	259.8	
Female	45-54	135.0	141.8	150.0	163.9	300.2	
	55-64	144.1	150.2	160.1	174.1	300.2	
	65-74	150.2	159.8	166.2	180.0	280.0	

DBP Deciles

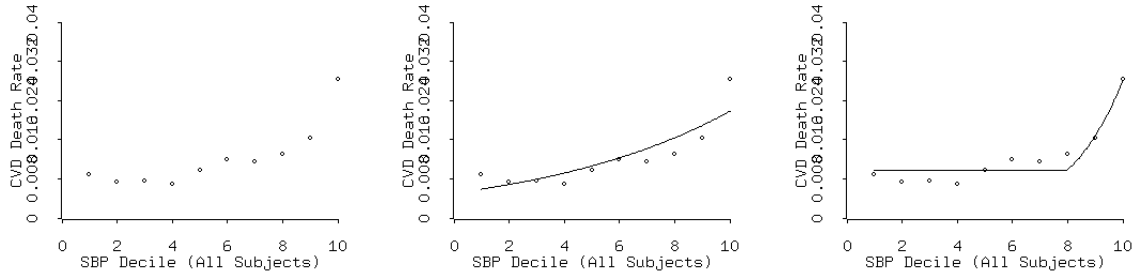
	Age	Min	10%	20%	30%	40%	Median
Male	45-54	20.1	70.0	75.0	79.8	80.1	83.9
	55-64	32.2	69.8	73.8	77.9	80.0	82.0
	65-74	30.2	67.8	70.0	74.0	77.9	80.0
Female	45-54	48.0	69.8	72.0	76.0	79.8	80.2
	55-64	44.8	69.8	71.9	76.1	79.9	81.8
	65-74	29.9	67.8	70.1	74.0	78.0	80.0

*The research covered in this report is directed by Noel Boyle, MD, PhD, Stanley Franklin, MD, Robert Jennrich, PhD, and Sidney Port, PhD.

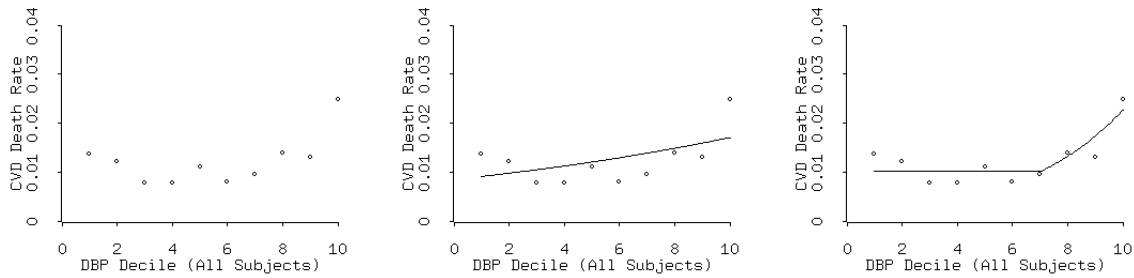
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	Age	60%	70%	80%	90%	Max
Male	45-54	86.1	89.9	94.0	100.0	160.2
	55-64	85.8	89.8	92.2	99.9	144.8
	65-74	82.1	86.0	90.0	94.2	144.8
Female	45-54	84.1	88.9	91.9	98.2	159.9
	55-64	84.9	88.2	92.1	99.8	160.1
	65-74	82.2	86.0	90.0	96.0	144.1

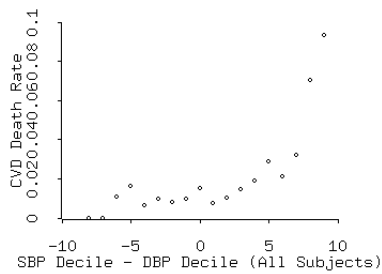
Risk of Cardiovascular Death vs. SBP Decile, All Patient Visits, with Linear and Spline Fits Overlaid



Risk of Cardiovascular Death vs. DBP Decile, All Patient Visits, with Linear and Spline Fits Overlaid



Risk of Cardiovascular Death vs. Difference Between SBP and DBP Deciles, All Patient Visits



The multiple logistic spline regression model

$$\text{logit}(\text{Risk}) = \alpha_i + \beta_1(\text{SBPdecile} - 8)_+ + \beta_2(\text{DBPdecile} - 7)_+ + \beta_3(\text{SBPdecile} - \text{DBPdecile} - 1)_+$$

Results of model

Data Set: WORK.TMP
 Response Variable: CVSURVIV
 Response Levels: 2
 Number of Observations: 46369
 Link Function: Logit

Response Profile

Ordered Value	CVSURVIV	Count
1	0	572
2	1	45797

Model Fitting Information and Testing Global Null Hypothesis BETA=0

Criterion	Without Covariates	With Covariates	Chi-Square for Covariates
AIC	64281.083	5756.702	.
SC	64281.083	5835.402	.
-2 LOG L	64281.083	5738.702	58542.381 with 9 DF (p=0.0001)
Score	.	.	44131.682 with 9 DF (p=0.0001)

Analysis of Maximum Likelihood Estimates

Variable	DF	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square	Standardized Estimate	Odds Ratio
A1	1	-5.2537	0.1409	1389.7265	0.0001	-1.050875	0.005
A2	1	-4.2950	0.0907	2240.6556	0.0001	-0.908671	0.014
A3	1	-3.9305	0.1009	1517.9057	0.0001	-0.642564	0.020
A4	1	-6.2932	0.2054	938.9754	0.0001	-1.375033	0.002
A5	1	-5.4698	0.1296	1780.3196	0.0001	-1.273926	0.004
A6	1	-4.4785	0.1073	1743.4586	0.0001	-0.855613	0.011
SBP_8	1	0.2998	0.0685	19.1475	0.0001	0.105861	1.350
DBP_7	1	0.2365	0.0497	22.6549	0.0001	0.132983	1.267
PP_1	1	0.2012	0.0311	41.9262	0.0001	0.122528	1.223

Association of Predicted Probabilities and Observed Responses

Concordant = 70.7% Somers' D = 0.476
 Discordant = 23.1% Gamma = 0.507
 Tied = 6.1% Tau-a = 0.012
 (26195884 pairs) c = 0.738

Parameter Estimates and 95% Confidence Intervals

Variable	Parameter Estimate	Profile Likelihood Confidence Limits	
		Lower	Upper
A1	-5.2537	-5.5407	-4.9873
A2	-4.2950	-4.4764	-4.1206
A3	-3.9305	-4.1326	-3.7369
A4	-6.2932	-6.7220	-5.9136
A5	-5.4698	-5.7327	-5.2239
A6	-4.4785	-4.6938	-4.2731
SBP_8	0.2998	0.1652	0.4338
DBP_7	0.2365	0.1381	0.3329
PP_1	0.2012	0.1390	0.2609

Modeled odds ratio for ten hypothetical case studies

Subject	Age	SBP	DBP	Odds Ratio
Sam	47	130	70	1.8
Marvin	51	130	85	1.0
Jack	45	140	70	2.7
Peter	49	150	90	1.6
David	50	150	70	5.5
Mary	69	140	70	1.2
Alice	67	164	84	1.0
Sally	72	160	80	1.2
Sarah	68	160	90	1.3
Kathy	70	172	70	4.2

Comparison of hypertension diagnosis rates

Conventional Diagnosis	New Model	Male		
		45-54	55-64	65-74
Normal	Normal	58%	54%	48%
Hypertensive	Normal	7	10	13
Normal	Hypertensive	6	5	5
Hypertensive	Hypertensive	29	32	34
Conventional Diagnosis	New Model	Female		
		45-54	55-64	65-74
Normal	Normal	61%	51%	41%
Hypertensive	Normal	5	14	19
Normal	Hypertensive	5	3	2
Hypertensive	Hypertensive	28	32	38

Odds Ratios by SBP Decile and DBP Decile

10	9.1	7.4	6.1	5.0	4.1	3.3	2.7	2.8	2.9	3.7
9	5.5	4.5	3.7	3.0	2.5	2.0	1.7	2.2	2.7	1.0
8	3.3	2.7	2.2	1.8	1.5	1.2	1.0	1.3	1.6	2.0
7	2.7	2.2	1.8	1.5	1.2	1.0	1.0	1.3	1.6	2.0
SBP 6	2.2	1.8	1.5	1.2	1.0	1.0	1.0	1.3	1.6	2.0
Decile 5	1.8	1.5	1.2	1.0	1.0	1.0	1.0	1.3	1.6	2.0
4	1.5	1.2	1.0	1.0	1.0	1.0	1.0	1.3	1.6	2.0
3	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.3	1.6	2.0
2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.3	1.6	2.0
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.3	1.6	2.0
	1	2	3	4	5	6	7	8	9	10
	DBP Decile									