Epidemiology of Metabolic Acidosis in Chronic Kidney Disease

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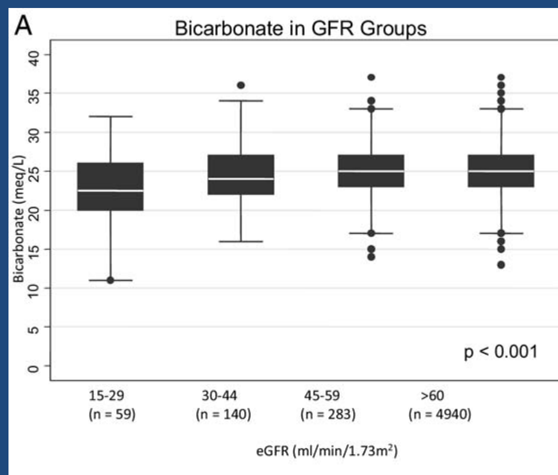
Objectives

- Discuss the prevalence of metabolic acidosis in patients with chronic kidney disease.
- Discuss associations of acidosis with clinical and biochemical factors.
- Discuss the association of serum bicarbonate levels with mortality in dialysis patients.
- Discuss the association of serum bicarbonate levels with progression of kidney disease.

Serum bicarbonate levels by CKD stage



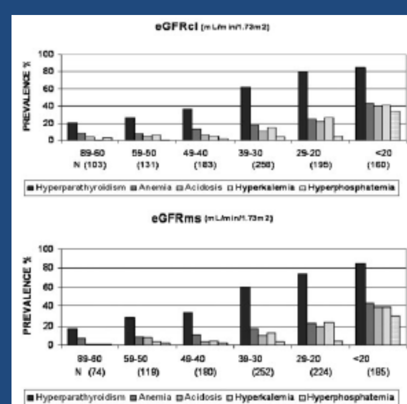
Shah et al. AJKD 2009; 54:270-277

Onset of metabolic acidosis

Table 2. Prevalence of metabolic complications[a] in the cohort

	Prevalence of Complications		Prevalence of Treatment among Patients with Complications	
	n	%	*n*	%
Hyperparathyroidism	610	59	87	14
Anemia	210	20	37	18
Acidosis	160	15	35	22
Hyperkalemia	176	17	87	49
Hyperphosphatemia	84	8	32	38

[a]Hyperparathyroidism was defined as a PTH >60 pg/ml or active vitamin D treatment; anemia was defined as Hb<110 g/L according to K/DOQI-based criteria or erythropoiesis-stimulating agent (ESA) treatment; acidosis was defined a tCO_2 <22 mmol/L) or bicarbonate treatment; hyperkalemia was defined as plasma potassium concentration >5 mmol/L or ion exchange resin treatment; hyperphosphatemia was defined as plasma phosphate concentration >4.3 mg/dl (1.38 mmol/L) or phosphate binder treatment.



Moranne et al. JASN 2009

Prevalence of acidosis by CKD stage in a CKD cohort

Table 2. Plasma albumin and total CO_2 concentrations and distributions in the stages of CKD

Parameter	CKD Stage 3	CKD Stage 4	CKD Stage 5	*P*
Whole population (*n*)	356	254	81	–
albumin (g/L)	40.2 ± 5.1	39.0 ± 5.5	39.0 ± 5.7	0.007
total CO_2 (mmol/L)	26.3 ± 2.9	24.3 ± 3.0	22.8 ± 3.4	<0.001
Plasma albumin <35 g/L (*n*)	40	50	18	
% of respective CKD stage	11.2	19.7	22.2	0.004
Total CO_2 < 22 mmol/L (*n*)	25	49	35	
% of respective CKD stage	7.0	19.3	43.2	<0.001

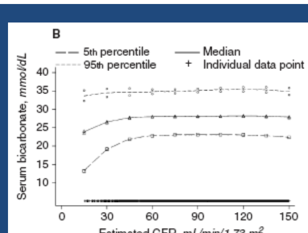
Moranne et al. JASN 2009

Prevalence of acidosis by CKD stage in the general population

Table 2. Estimated United States population laboratory results by glomerular filtration rate (GFR) category: NHANES III 1988–1994

	Sample *N*	Total	Estimated GFR category *mL/min/1.73 m²* 15–29	30–59	60–89	90–150	>150	*P* value[a]
Mean serum albumin *g/dL*	15,594	4.18	3.83[b]	4.02	4.17[d]	4.23	3.97[d]	<0.001
Serum albumin <3.8 g/dL %	2171	10.9	51.2[d]	20.4	9.9[c]	9.2	28.3[d]	<0.001
Serum albumin <3.5 g/dL %	584	2.6	8.2	6.2[b]	2.2	1.7	17.3[d]	<0.001
Mean serum bicarbonate *mmol/L*	15,594	28.1	24.6[d]	28.2[c]	28.3	28.1	27.0	<0.001
Bicarbonate <22 mmol/L %	362	1.7	19.1[d]	2.3	1.3	1.6	6.0[d]	<0.001
Serum anion gap *mmol/L*	15,594	8.68	11.04[c]	9.40[c]	8.74	8.61	8.36	0.02
C-reactive protein >0.21 mg/dL %	5427	39.5	57.7	48.7[c]	30.5	25.1	31.9[b]	<0.001
Alanine aminotransferase *U/L*	1642	10.1	–	3.0[b]	9.0	10.9	14.2	<0.001
Aspartate aminotransferase *U/L*	1813	9.6	8.5	7.1	8.9	9.8	15.1[c]	0.02
Mean total cholesterol *mg/dL*	15,555	204.1	227.4	230.6	213.2[c]	195.5	191.7	<0.001
Urinary albumin:creatinine ratio >1000 mg/g %	106	0.3	18.1[d]	2.4[d]	0.5[b]	0.1	0.01	<0.001

[a] *P* value for difference among categories of estimated GFR (4 degrees of freedom).
P values for individual GFR categories versus GFR 90–150 mL/min/1.73 m² after adjustment for age, sex, and race, which differ markedly across categories of estimated GFR are: [b] $P < 0.05$, [c] $P < 0.01$, and [d] $P < 0.001$.



Eustace et al. KI 2004

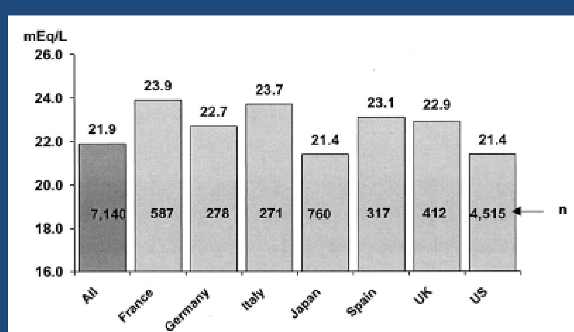
Prevalence of acidosis varies by race and ethnicity

Table 4. Unadjusted OR of BP and laboratory variables ≤5th or ≥95th percentiles, compared by categories of GFR and race/ethnicity*

Variable	GFR: <60 versus ≥60 ml/min per 1.73 m^2	GFR: P	Race/Ethnicity (versus White): Black	Race/Ethnicity (versus White): Hispanic	Race/Ethnicity (versus White): Other	P: Race/Ethnicity	P: Race/Ethnicity × GFR
SBP ≥156.0 mmHg							
all	5.60 (4.47 to 7.02)	<0.0001	1.53 (1.25 to 1.88)	0.71 (0.58 to 0.87)	0.86 (0.56 to 1.31)	<0.0001	<0.0001
GFR <60			1.84 (1.27 to 2.66)	1.97 (1.13 to 3.44)	2.20 (1.35 to 3.58)	0.0005	
GFR ≥60			1.61 (1.31 to 2.05)	0.76 (0.63 to 0.92)	0.79 (0.55 to 1.14)	<0.0001	
DBP ≥90.7 mmHg							
all	1.54 (1.09 to 2.16)	0.0147	1.93 (1.52 to 2.46)	0.95 (1.52 to 2.46)	1.01 (0.67 to 1.53)	<0.0001	0.0010
GFR <60			3.01 (1.79 to 5.05)	1.77 (1.79 to 5.05)	5.27 (1.91 to 14.55)	0.0004	
GFR ≥60			1.89 (1.47 to 2.43)	0.95 (0.73 to 1.22)	0.87 (0.58 to 1.31)	<0.0001	
Potassium ≥4.6 mmol/L							
all	4.03 (3.15 to 5.16)	<0.0001	0.75 (0.57 to 0.90)	0.63 (0.45 to 0.90)	0.65 (0.40 to 1.08)	0.0060	0.0006
GFR <60			0.72 (0.36 to 1.43)	1.29 (0.73 to 2.28)	1.92 (1.22 to 3.01)	0.0139	
GFR ≥60			0.79 (0.60 to 1.04)	0.68 (0.48 to 0.96)	0.58 (0.34 to 0.98)	0.0229	
Hemoglobin ≤118.0 g/L							
all	2.21 (1.69 to 2.90)	<0.0001	3.44 (2.46 to 4.82)	1.37 (0.96 to 3.39)	1.29 (0.77 to 2.17)	<0.0001	0.7936
GFR <60			3.96 (2.66 to 5.88)	1.77 (0.88 to 3.59)	1.77 (0.88 to 3.59)	<0.0001	
GFR ≥60			3.54 (2.41 to 5.19)	1.45 (0.97 to 2.17)	1.38 (0.78 to 2.42)	<0.0001	
Bicarbonate ≤22.5 mmol/L							
all	1.77 (1.27 to 2.48)	0.0013	1.52 (1.10 to 2.09)	2.03 (1.22 to 3.39)	0.73 (0.39 to 1.38)	0.0010	0.8822
GFR <60			1.44 (0.73 to 2.87)	2.34 (1.09 (5.05)	0.92 (0.09 to 9.52)	0.1344	
GFR ≥60			1.55 (1.12. to 2.15)	2.11 (1.25 to 2.15)	0.74 (0.36 to 1.54)	0.0012	

Foley et al. JASN 2007

Distribution of serum bicarbonate in hemodialysis patients by country



Bommer et al. AJKD 2004; 44:661-671

Sample handling affects bicarbonate measurement

Table 1. Measured Parameters for 24 Hemodialysis Patients

Parameter	Set 1	Set 2	Set 3RT	Set 3FR
Sodium (mEq/L)	140 ± 3	138 ± 3	139 ± 2	138 ± 4
Potassium (mEq/L)	4.9 ± 0.6	4.7 ± 0.6	4.6 ± 0.7	4.6 ± 0.6
Chloride (mEq/L)	100 ± 4	98 ± 3	98 ± 4	97 ± 5
tCO_2 (mEq/L)	17 ± 3	22 ± 3	22 ± 3	23 ± 3
AG (mEq/L)	28 ± 4	22 ± 4	24 ± 4	23 ± 3
Lactate (mEq/L)	—	2.4 ± 0.6	3.7 ± 0.8	4.0 ± 0.7
d-tCO_2 (mEq/L)	—	5.2 ± 2.0	—	—
d-AG (mEq/L)	—	5.8 ± 2.2	—	—
BUN (mg/dL)	70 ± 15	—	—	—
Creatinine (mg/dL)	12.4 ± 2.8	—	—	—
Glucose (mg/dL)	125 ± 60	—	—	—
LDH (U/L)	213 ± 80	—	—	—
Hgb (g/dL)	12.1 ± 1.3	—	—	—
WBC (×10^9/L)	6.5 ± 1.9	—	—	—

Abbreviations: RT, storage at room temperature; FR, storage in refrigerator; d-tCO_2, differences in tCO_2 between set 2 and set 1; d-AG, difference in AG between set 1 and set 2; LDH, lactate dehydrogenase; WBC, white blood cells.

Kirschbaum B. AJKD 2000

Sample handling affects bicarbonate measurement

Table 1. Total Carbon Dioxide Results in Hemodialysis Patients: Impact of the Assay

	Total Carbon Dioxide Measurements (mEq/L)	
	Initial Blood Samples	Subsequent Samples*
Local laboratory (pH electrode)	21.8 ± 0.3	22.2 ± 0.7
Reference laboratory (enzymatic technique)	16.4 ± 0.3†	18.7 ± 0.8‡

* Subsequent samples refers to total carbon dioxide measurements on samples after the reference laboratory was alerted of the results in column one.

† $P < 0.01$, local *v* reference laboratory.

‡ $P < 0.05$, local *v* reference laboratory.

Bray et al. AJKD 1996

Objectives

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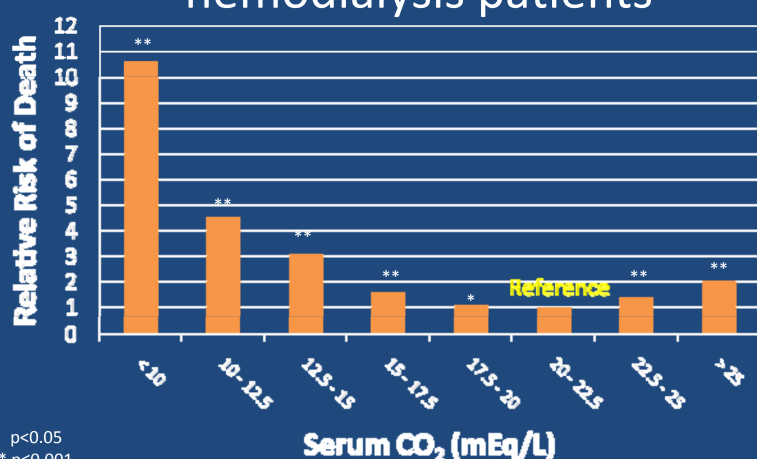
- Discuss the association of serum bicarbonate levels with progression of kidney disease.

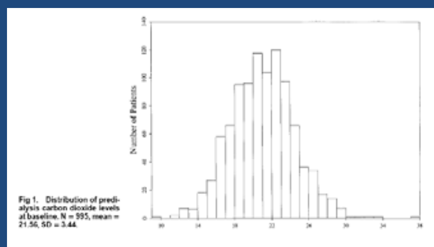
J-shaped association of bicarbonate level with mortality in 12,099 hemodialysis patients

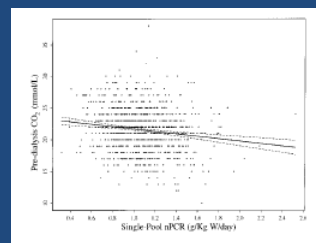


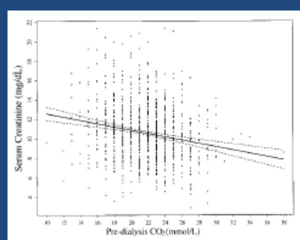
* $p<0.05$
** $p\leq0.001$

Lowrie et al. AJKD 1990; 15:458-482

Association of serum bicarbonate with nPCR & creatinine in the HEMO Study







Uribarri et al. AJKD 1999

Association of serum bicarbonate with albumin and nutritional parameters

Table 3. Association of Predialysis Serum Total Carbon Dioxide With Serum Chemistry, Nutritional, and Urea Kinetic Parameters

	Total CO_2 (mmol/L)			
	<21* (n = 376)	21-25 (n = 506)	>25 (n = 113)	Partial Correlation Coef (*P*)†
Single-pool nPCR (g/kg/d)	1.11	1.06	0.96	−0.16 (<0.001)
Equilibrated nPCR (g/kg/d)	1.03	0.99	0.89	−0.15 (<0.001)
Predialysis BUN (mg/dL)	59.53	57.90	51.12	−0.16 (<0.001)
Reported dietary protein intake (g/kg/d)	0.94	0.94	0.88	−0.08 (0.02)
Reported caloric intake (cal/kg/d)	22.72	23.20	22.35	−0.04 (0.22)
Equilibrated Kt/V	1.31	1.30	1.28	+0.04 (0.21)
Ultrafiltration (L/dialysis)	2.82	2.84	2.79	−0.07 (0.04)
Serum creatinine (mg/dL)	11.28	10.41	9.56	−0.18 (<0.001)
Serum albumin (g/dL)	3.70	3.65	3.62	−0.05 (0.12)
Serum potassium (mmol/L)	4.91	4.82	4.61	−0.12 (<0.001)
Serum phosphorus (mg/dL)	6.27	5.56	4.82	−0.32 (<0.001)
Age (y)	56.24	58.23	59.52	+0.10 (0.002)
Duration of dialysis (y)	4.02	4.23	4.94	+0.04 (0.23)
Weight (kg)	68.26	69.88	67.78	+0.02 (0.54)
Biceps skinfold (mm)	9.24	10.20	8.99	−0.03 (0.38)
Supscapular skinfold (mm)	16.48	17.74	16.07	−0.02 (0.49)
Triceps skinfold (mm)	15.78	16.33	14.42	−0.05 (0.14)
Body mass index	25.14	25.66	24.23	−0.02 (0.52)

NOTE. Serum total carbon dioxide was not significantly associated with race, sex, cause of renal disease, or diabetic status.

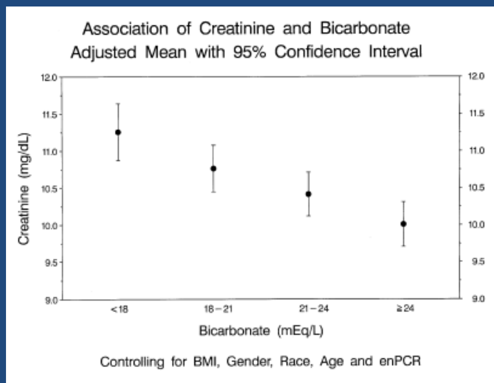
Abbreviation: CO_2, carbon dioxide.

*Means of indicated parameters are provided for the CO_2 subgroups.

†Pearson's partial correlation coefficients are adjusted for day of the week and dialysis unit.

Uribarri et al. AJKD 1999

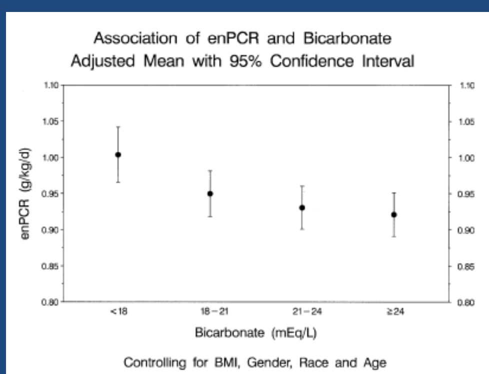
Inverse association of serum bicarbonate & creatinine in the HEMO Study



	Change in creatinine (mg/dL)	P
Baseline bicarbonate	-0.107 ± 0.020	< 0.001
Change in bicarbonate	-0.153 ± 0.015	< 0.001

Kaysen et al. AJKD 2003; 42:1200-1211

Association of serum bicarbonate with baseline PCR & albumin in HEMO



	Baseline Bicarbonate	P
Change in PCR	-0.004 ± 0.001	0.011
Change in albumin	0.002 ± 0.002	0.409

Kaysen et al. AJKD 2003; 42:1200-1211

Association of bicarbonate with albumin is attenuated by adjustment for nPNA in USRDS Wave 1

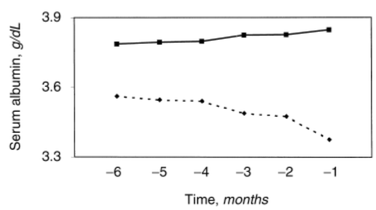


Fig. 1. Serum albumin during the six months before death for nonsurvivors (◆; 350 patients who died during one year of follow-up) compared with serum albumin during the six months prior to study start in 1476 prevalent ESRD patients (■; duration of ESRD >6 months at baseline) who remained alive through to the end of the one-year follow-up.

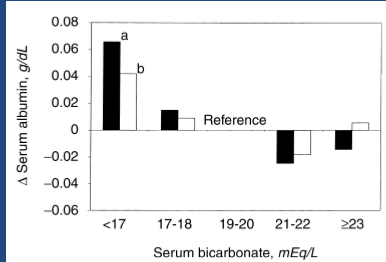


Fig. 3. A linear inverse relationship existed between the predialysis serum albumin and the serum bicarbonate concentrations at baseline. Following the addition of nPNA as a covariate to the multivariate analysis, the linear relationship between serum albumin and serum bicarbonate was no longer significant. Albumin was highest in the low bicarbonate groups without (■; $P = 0.0005$) or with (□; $P = 0.1239$) an adjustment for nPNA ([a]$P = 0.005$; [b]$P = 0.076$ vs. reference group).

Leavey et al. KI 2000

Association of serum bicarbonate with hypoalbuminemia in the general population

Table 4. Crude and adjusted odds ratios of hypoalbuminemia (<3.8 mg/dL): NHANES III 1988–1994

	Crude			Adjusted		
	Odds ratio	95% CI	*P* value	Odds ratio	95% CI	*P* value
Age, 10 *years*	1.22	1.17, 1.28	<0.001	1.30	1.23, 1.37	<0.001
Female gender	3.67	3.05, 4.41	<0.001	3.18	2.60, 3.89	<0.001
Race						
Non-Hispanic white	1.0	Referent		1.0	Referent	
Non-Hispanic black	2.39	1.87, 3.05	<0.001	2.12	1.67, 2.69	<0.001
Mexican-American	1.06	0.80, 1.40	0.70	0.96	0.74, 1.24	0.73
Other	1.23	0.89, 1.71	0.21	1.26	0.87, 1.83	0.22
Estimated glomerular filtration rate *mL/min/1.73m²*						
>150	3.92	3.05, 5.04	<0.001	3.50	0.91, 1.74	<0.001
90–150	1.0	Referent		1.0	Referent	
60–89	1.05	0.89, 1.23	0.57	0.76	0.63, 0.93	0.007
30–59	2.43	1.87, 3.15	<0.001	0.91	0.65, 1.27	0.56
15–29	9.93	4.14, 23.8	<0.001	2.82	0.83, 9.61	0.10
Diabetes mellitus	2.41	1.88, 3.08	<0.001	1.26	0.91, 1.74	0.16
Hypertension	1.48	1.21, 1.80	<0.001	0.71	0.58, 0.87	0.002
Serum bicarbonate mmol/L						
>28	1.0	Referent		1.0	Referent	
26–28	1.29	1.03, 1.60	0.03	1.25	0.99, 1.58	0.06
23–25	1.66	1.36, 2.03	<0.001	1.51	1.21, 1.87	0.001
≤22	2.16	1.54, 3.04	<0.001	1.54	1.08, 2.18	0.02

Eustace et al. KI 2004

Change in albumin with correction of acidosis

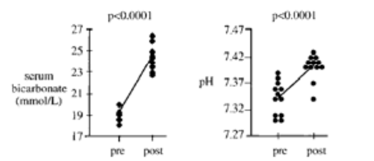


Fig. 1. Changes in serum bicarbonate levels and arterial pH before and after the correction of acidosis.

Table 2. Changes in serum albumin, PCRn, Kt/V, TACurea, total serum proteins, and serum creatinine levels before and after the correction of acidosis

Parameter	Pre	*P*	Post
Serum Albumin (g/l)	34.9 ± 2.1	0.01	37.9 ± 2.9
PCRn (g/kg/day)	1.11 ± 0.17	0.001	1.03 ± 0.17
Kt/V	1.26 ± 0.14	NS	1.26 ± 0.12
TACurea (mmol/l)	7.5 ± 1.7	NS	7.3 ± 1.3
Total serum proteins (g/dl)	6.4 ± 0.6	NS	6.5 ± 0.3
Serum creatinine (mmol/l)	937 ± 283	NS	1017 ± 212

Table 1. Changes in plasma sodium, haemoglobin, body weight, pre-HD systolic and diastolic blood pressure and intradialytic weight loss before and after the correction of acidosis

Parameter	Pre	*P*	Post
Plasma sodium (mmol/l)	139 ± 2.8	NS	140 ± 2.6
Haemoglobin (g/dl)	11.5 ± 1.4	NS	11.5 ± 0.9
Body weight (kg)	66 ± 11	NS	67 ± 11
Pre-HD systolic BP (mmHg)	147 ± 8	NS	150 ± 15
Pre-HD diastolic BP (mmHg)	82 ± 4	NS	82 ± 7
Intra-HD weight loss (kg)	2.1 ± 0.4	NS	2.0 ± 0.6

Movilli et al. NDT 1998

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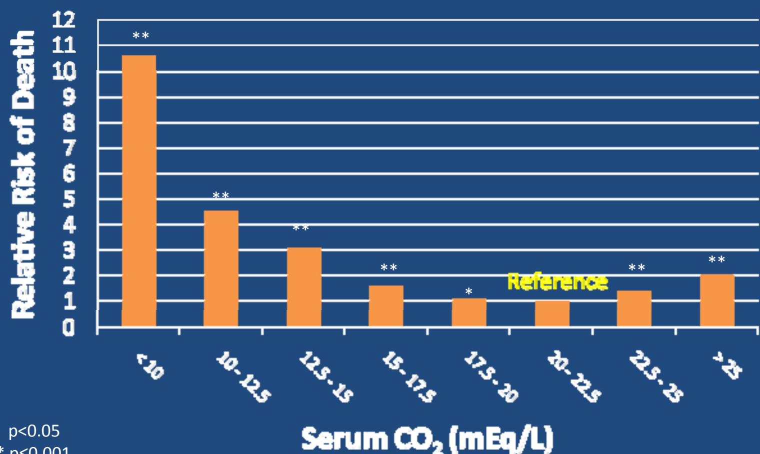
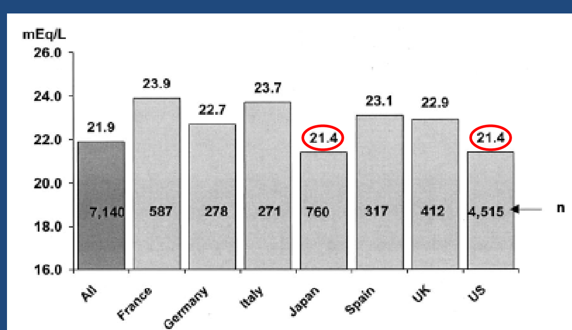
Relative risk of death by bicarbonate level in 12,099 hemodialysis patients



* p<0.05
** p≤0.001

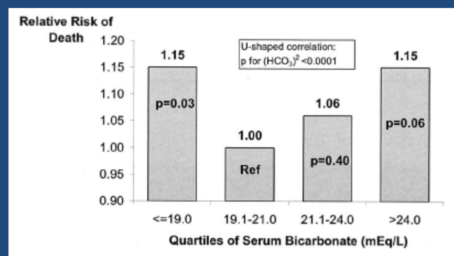
Lowrie et al. AJKD 1990; 15:458-482

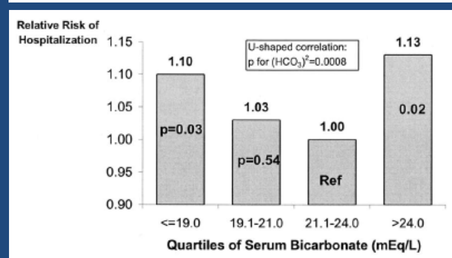
Importance of factors other than serum bicarbonate level



Bommer et al. AJKD 2004; 44:661-671

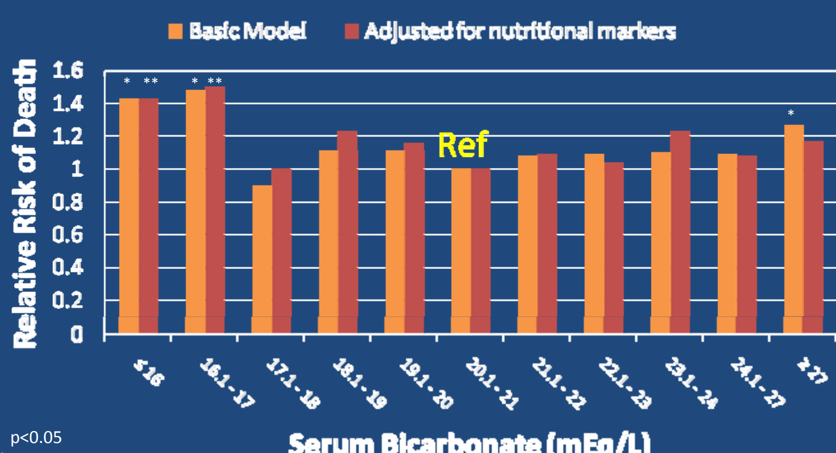
High and low bicarbonate levels associate with poor outcomes





Bommer et al. AJKD 2004; 44:661-671

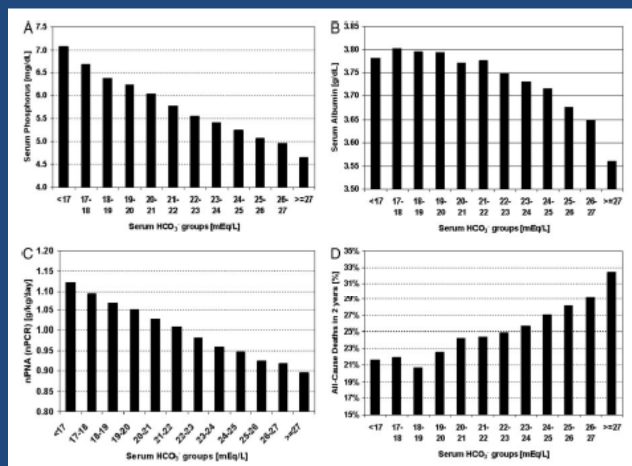
Effect of adjustment for nutritional markers on associations with mortality



* p<0.05
** p<0.01

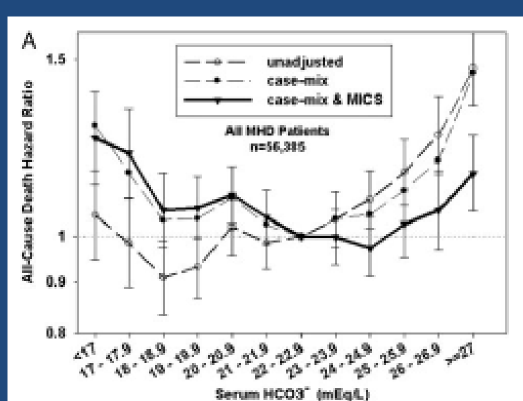
Bommer et al. AJKD 2004; 44:661-671

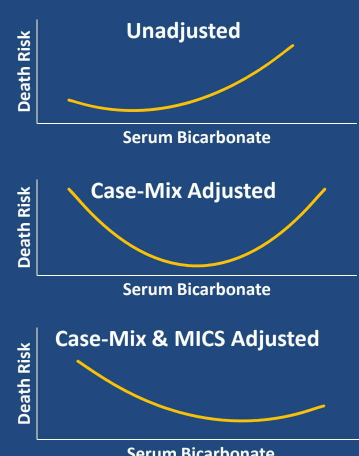
Higher bicarbonate levels associated with lower levels of nutritional markers and greater mortality in 56,385 HD patients



Wu et al. CJASN 2006; 1:70-78

Adjustment for markers of protein-energy malnutrition & inflammation changes the pattern of association





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Objectives

- Discuss the prevalence of metabolic acidosis in patients with chronic kidney disease.
- Discuss associations of acidosis with clinical and biochemical factors.
- Discuss the association of serum bicarbonate levels with mortality in dialysis patients.
- Discuss the association of serum bicarbonate levels with progression of kidney disease.

Effect of dietary protein on bicarbonate levels in MDRD

Table 1. Effect of GFR on serum [total CO_2] for all screened patients (1782)[a]

GFR Range (ml/min per 1.73 m^2)	N	[Total CO_2] (mEq/L)[b]
18 or less	258	21.0 ± 3.9
19 to 25	246	22.2 ± 3.7
26 to 40	514	23.2 ± 3.6
41 to 55	374	24.6 ± 3.3
>55	390	25.3 ± 3.2

[a]Data are shown as means ± 1 SD. Includes patients without measurements of estimated protein intake (EPI).
[b]Mean [total CO_2] differed significantly among the indicated GFR ranges ($P < 0.001$).

Table 2. Association of serum [total CO_2] with GFR and EPI[a] at baseline[b]

Predictor Variable	Δ[Total CO_2][c]	P
GFR (13 to 24 ml/min per 1.73 m^2) per 10 ml/min per 1.73 m^2	2.27 ± 0.22	<0.001
GFR (25 to 55 ml/min per 1.73 m^2) per 10 ml/min per 1.73 m^2	0.44 ± 0.05	<0.001
EPI per g/kg body wt per day	−0.91 ± 0.35	0.009

[a]Daily protein intakes estimated from urine urea nitrogen excretion.
[b]Multiple regression analysis controlling for clinical center. Clinical center was also statistically significant ($P < 0.001$).
[c]Estimated mean difference in serum [total CO_2] in mEq/L (± SE) associated with the indicated increases in GFR and EPI.

Gennari et al. CJASN 2006

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Table 5. Serum [total CO_2] at baseline and at 1 yr and the effect of the change in diet on [total CO_2] during that interval in the patients in study A and study B[a]

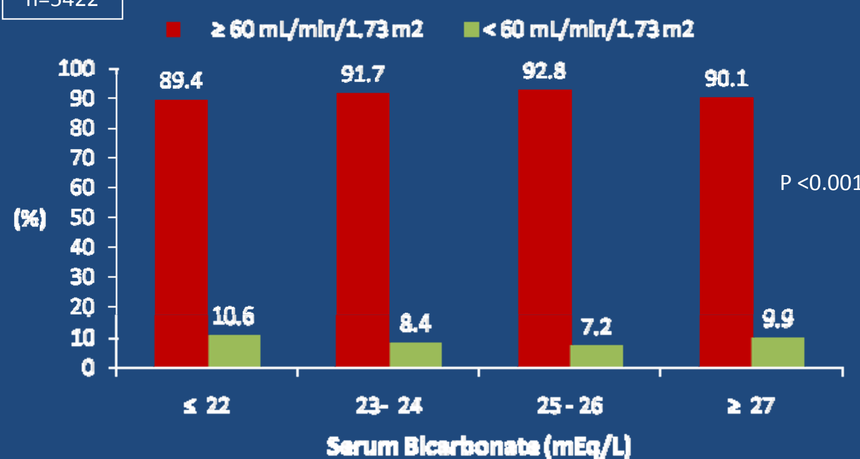
	Study A		Study B	
	Usual (n = 264)	Low (n = 253)	Low (n = 107)	Very Low (n = 99)
[Total CO_2] (mEq/L)				
entry	23.8 ± 3.6	24.2 ± 3.6	22.3 ± 3.7	21.6 ± 3.6
year 1	23.7 ± 3.3	24.9 ± 3.4	22.6 ± 3.6	22.8 ± 4.0
change[b]	−0.05 ± 0.27	0.86 ± 0.18[c]	0.40 ± 0.31	0.88 ± 0.32[c]
Diet effect[d] (mEq/L)		0.91 ± 0.25		0.48 ± 0.44

[a]ANCOVA with serum [total CO_2] as the dependent variable, EPI as the independent factor, and GFR as the potential confounding variable. Data shown for absolute values are ± 1 SD.
[b]Adjusted mean changes ± 1 SE, controlling for clinical center, the randomization stratification factors, baseline serum [total CO_2], and baseline GFR.
[c]$P < 0.01$ *versus* 0.
[d]Estimated diet effect (± 1 SE) on the change from baseline to 1 yr in serum [total CO_2] between the two diet groups in each study, controlling for clinical center, the randomization stratification factors, baseline serum [total CO_2], and baseline GFR (intention-to-treat analysis). $P < 0.001$ in study A; $P = 0.28$ in study B.

Gennari et al. CJASN 2006

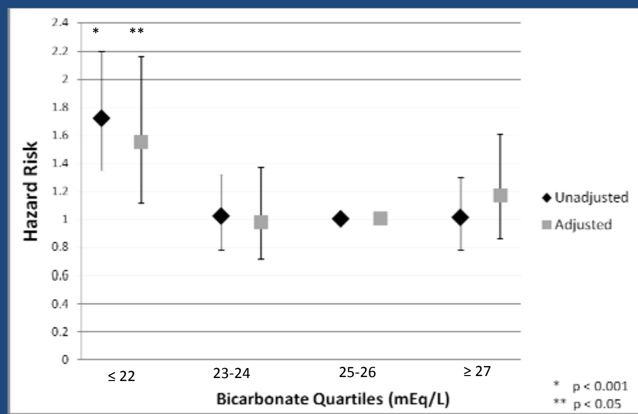
GFR range by bicarbonate quartiles in a Bronx cohort

n=5422



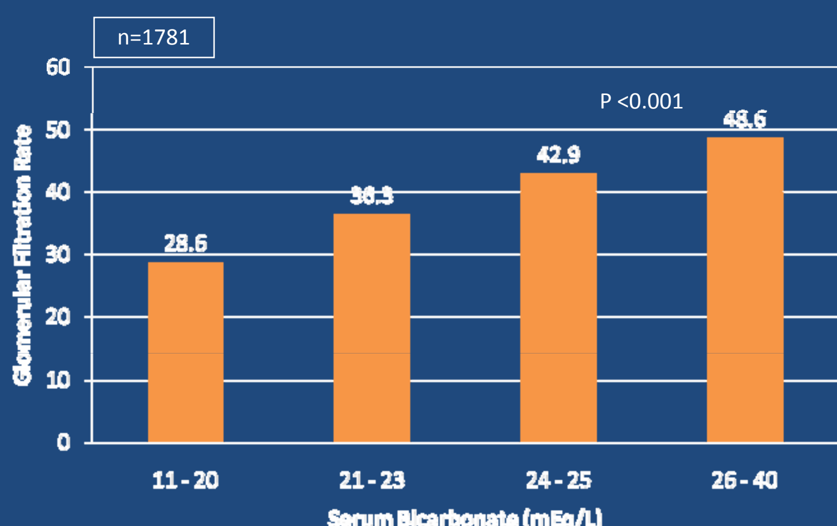
Shah et al. AJKD 2009; 54:270-277

Risk of kidney disease progression



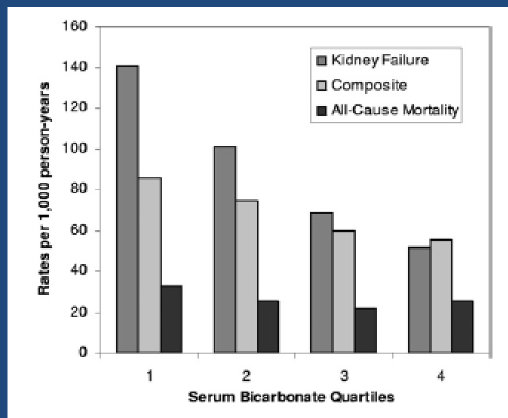
Shah et al. AJKD 2009; 54:270-277

GFR by serum bicarbonate in MDRD



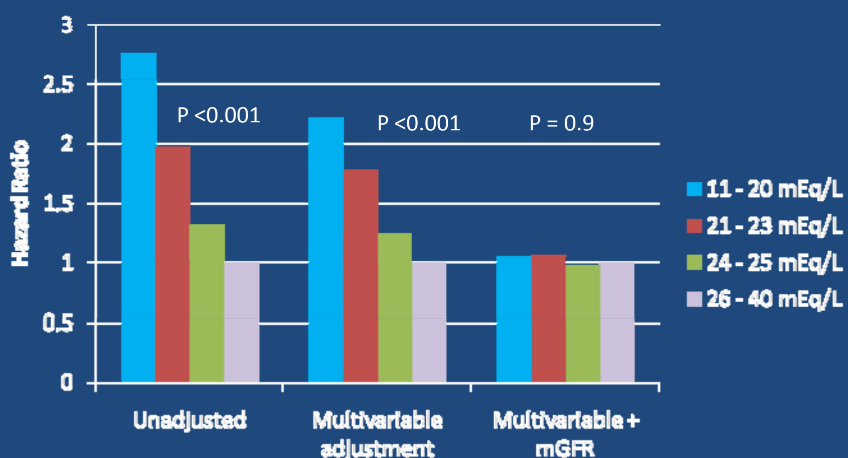
Menon et al. AJKD 2010

Incidence of mortality & kidney failure



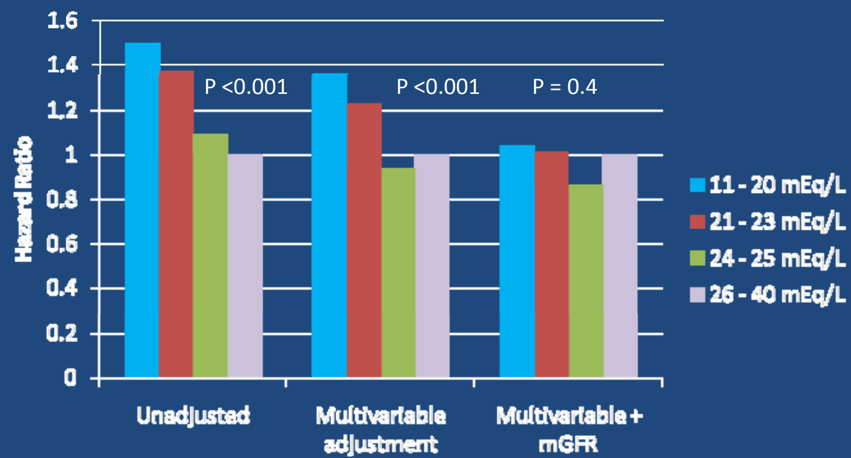
Menon et al. AJKD 2010

Risk of kidney failure is attenuated by adjustment for measured GFR



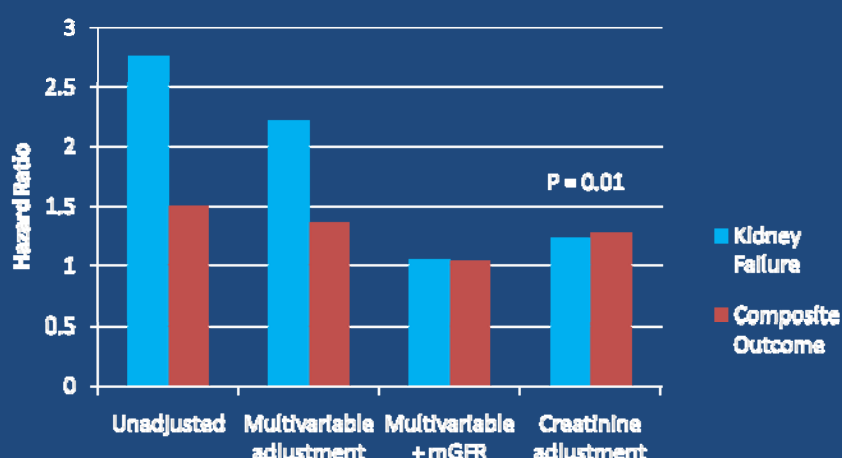
Menon et al. AJKD 2010

Risk of kidney failure or mortality also attenuated by adjustment for mGFR



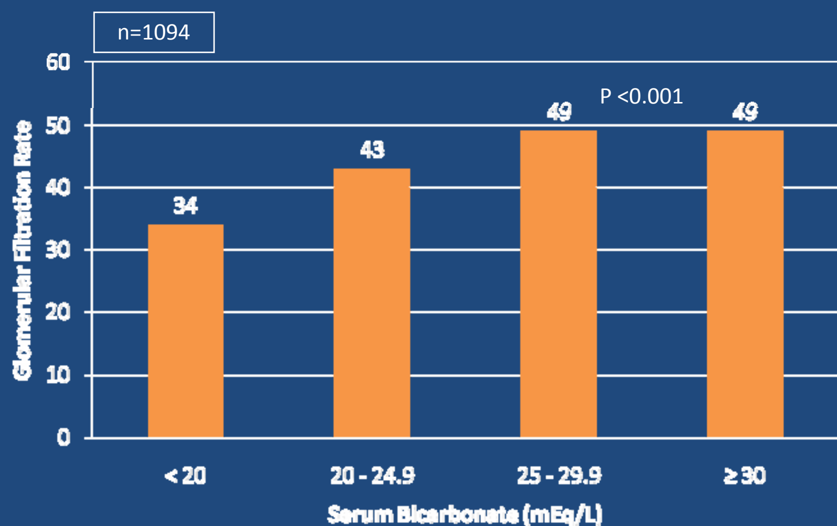
Menon et al. AJKD 2010

Effect of adjustment for creatinine instead of GFR



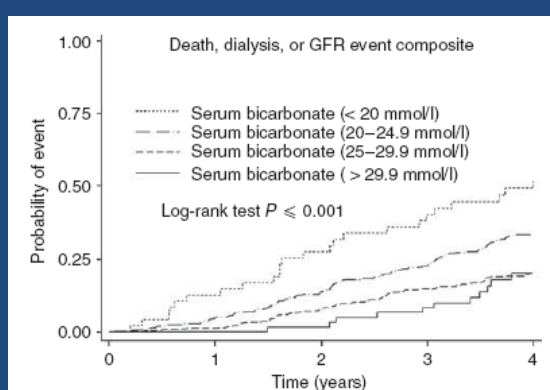
Menon et al. AJKD 2010

GFR by serum bicarbonate in AASK



Raphael et al. KI 2010; epub

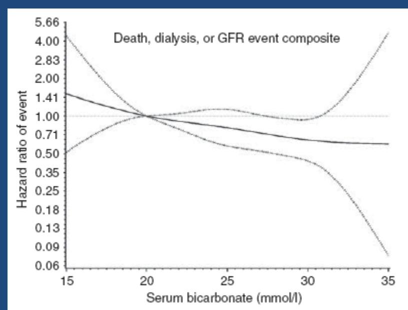
Probability of death, dialysis or GFR event by bicarbonate level

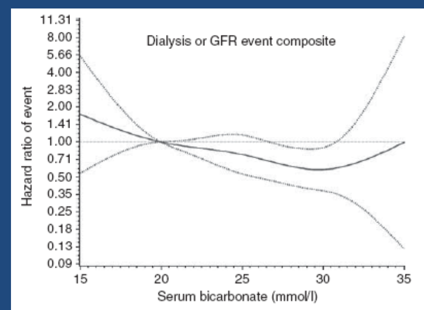


Raphael et al. KI 2010; epub

Higher bicarbonate levels are associated with better outcomes

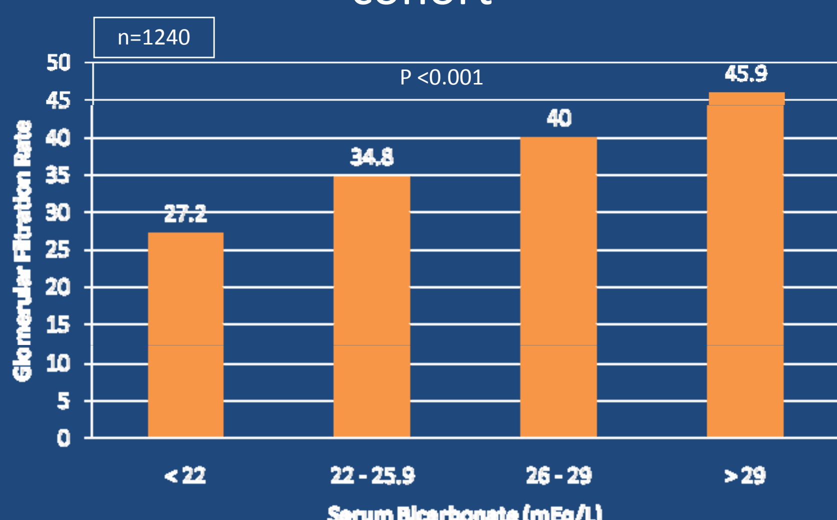
(or lower levels with worse outcomes)





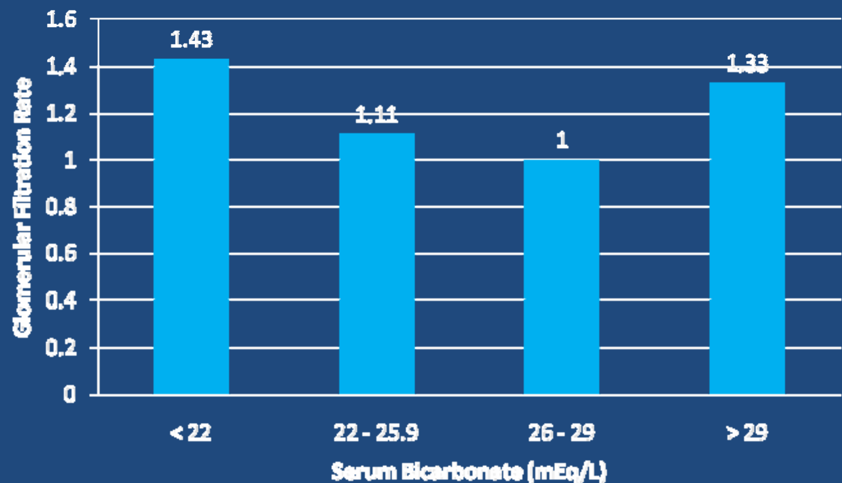
Raphael et al. KI 2010; epub

GFR by serum bicarbonate in a VA cohort



Kovesdy et al. NDT 2009; 24:1232-37

U-shaped association of serum bicarbonate with all-cause mortality

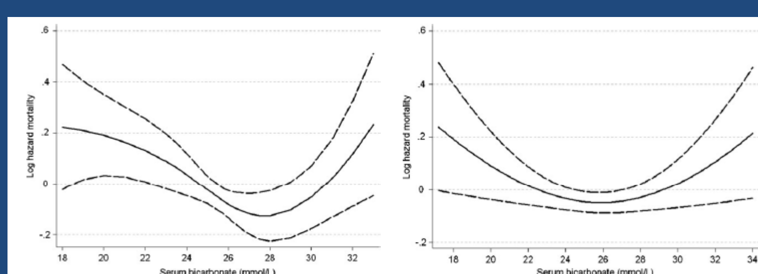


Kovesdy et al. NDT 2009; 24:1232-37

Association of serum bicarbonate with all-cause mortality

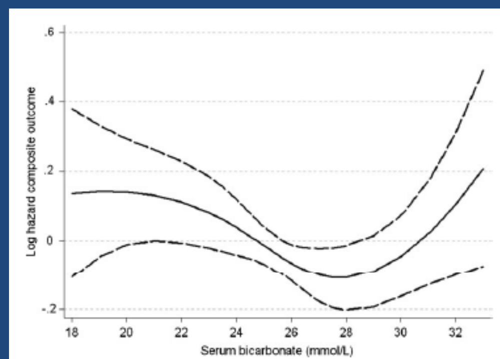
Baseline serum bicarbonate

Time-dependent serum bicarbonate



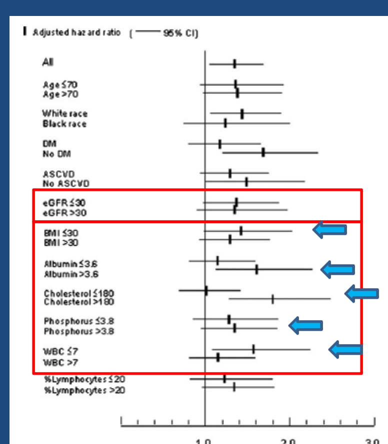
Kovesdy et al. NDT 2009; 24:1232-37

Association of serum bicarbonate with ESRD or pre-dialysis mortality



Kovesdy et al. NDT 2009; 24:1232-37

Effect of nutritional status on associations with mortality



Kovesdy et al. NDT 2009; 24:1232-37

Conclusions

- Associations of serum bicarbonate levels with nutritional parameters may differ between dialysis and non-dialysis patients.
- Low predialysis bicarbonate levels (<18 mEq/L) are independently associated with mortality in hemodialysis patients.
- High predialysis bicarbonate levels (>27 mEq/L) may be reflective of protein-energy wasting and inflammation and thus associated with poor outcomes.

Conclusions

- Lower serum bicarbonate levels are associated with greater risk of progression of kidney disease.
- This association may be causal, or lower bicarbonate levels may simply be a marker of advanced kidney disease.