HEMODIALYSIS COMPLICATIONS

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ACUTE PHYSICAL COMPLICATIONS

- HYPOTENSION 25-55%
- CRAMPS 5-20%
- NAUSEA 5-15%
- HEADACHES 5%
- CHEST PAIN 2-5 %
- BACK PAIN 2-5 %
- ITCHING 5%
- FEVER/CHILLS 1%

HEMOLYSIS

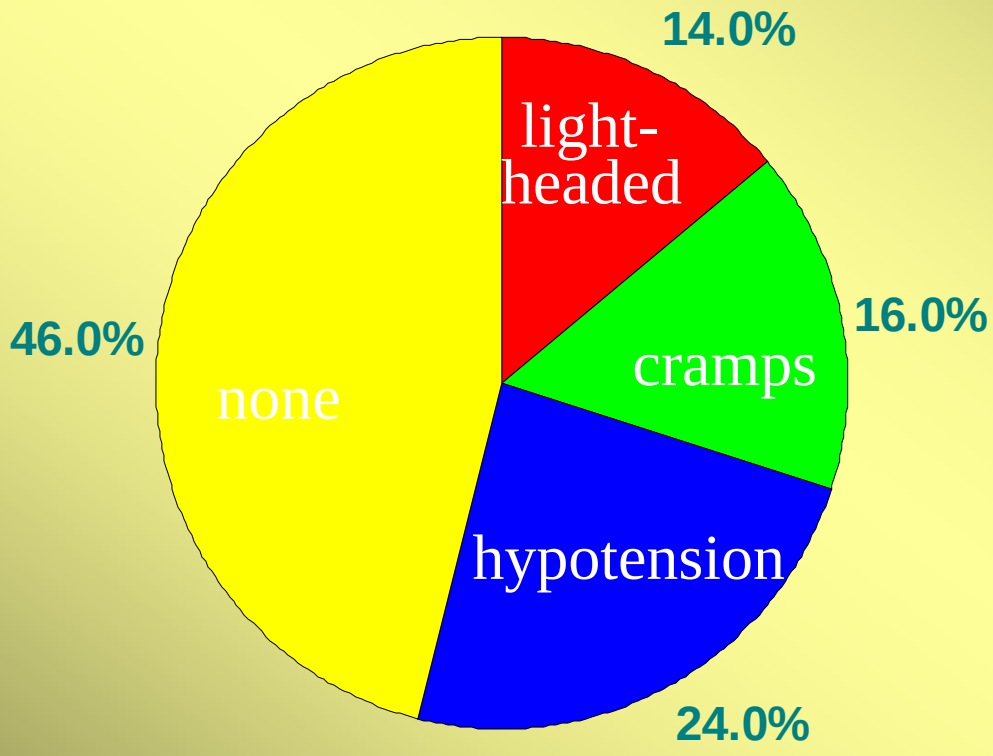
- SYMPTOMS
  - A port wine appearance of the blood in the venous line
  - Complaints of chest pain, shortness of breath, and/or back pain
  - A falling hematocrit
  - A pink color of the plasma in centrifuged specimens.
- CAUSES
  - Overheating
  - Hypotonicity due to an insufficient concentrate-to-water ratio
  - Contamination with formaldehyde, bleach, chloramine, or nitrates from the water supply, and copper from copper tubing or piping

OTHER COMPLICATIONS

- ARRHYTHMIAS
  - POTASSIUM AND CLACIUM
- AIR EMBOLISM
  - INEXCUSABLE
  - CORRECTED BY LEFT LATERAL DECUBITUS + LEG ELEVATION, 100% O_2, AND CPR
- ACCESS ISSUES
- HYPOTENSION

HYPOTENSION

COMPLICATIONS OF HEMODIALYSIS



FACTORS INFLUENCING HYPOTENSION

- PATIENT RELATED
  - COMORBID CONDITIONS
  - COMPLIANCE
  - MEDICATION
- PROCEDURE RELATED
  - DIALYSATE PROPERTIES
  - MEMBRANE
- PROCESS RELATED
  - MONITORS, EPO, EATING
  - ASSESSMENT OF DRY WEIGHT

CONSEQUENCES OF HYPOTENSION

- MYOCARDIAL INFARCTION
- CVA
- SYNCOPE / TRAFFIC ACCIDENTS
- REDUCED DELIVERY OF DIALYTIC THERAPY
- INABILITY TO ACHIEVE DRY WEIGHT

DETERMINANTS OF BLOOD PRESSURE

BLOOD PRESSURE = CARDIAC OUTPUT X SVR

STROKE VOL X HEART RATE

CONTRACTILITY ~ VENOUS RETURN

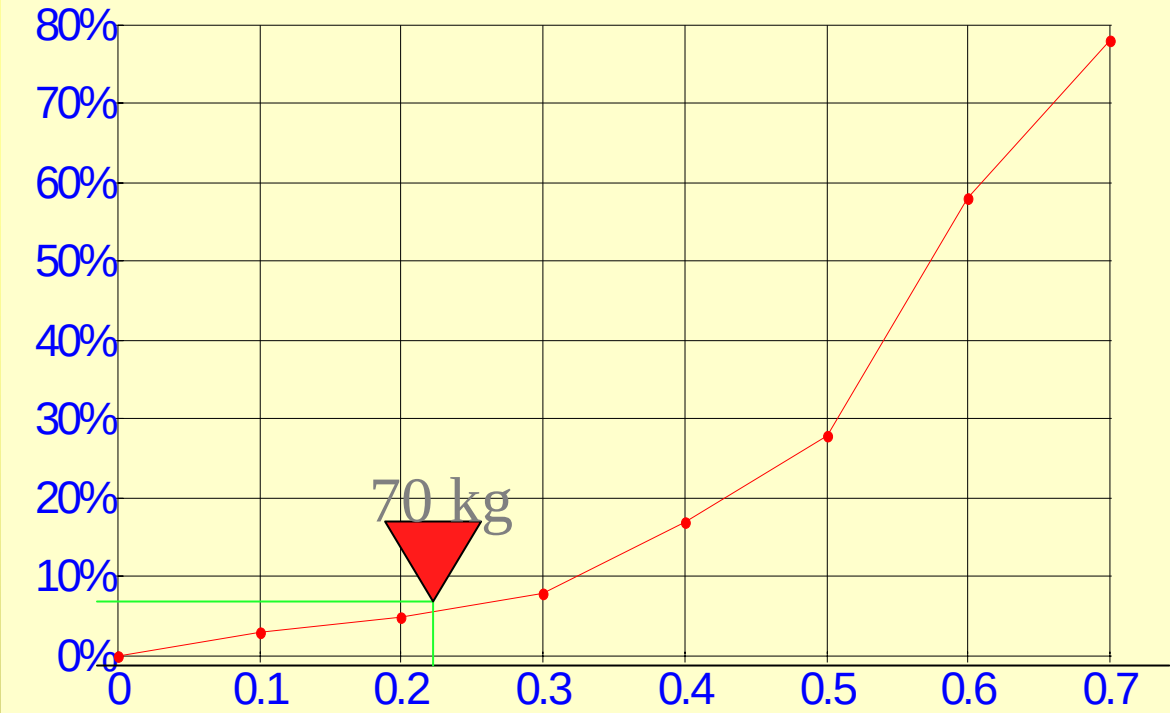
BLOOD VOLUME ~ VENOUS CAPACITANCE

CAUSES OF HYPOTENSION

- **DECREASES IN BLOOD VOLUME**
  - ABSOLUTE AND RELATIVE
  - HEMORRHAGE, SHIFTS, EXCESSIVE UF, EATING
- **CARDIAC CONTRACTILITY**
  - MYOCARDIAL DYSFUNCTION, MI, PERICARDITIS, ARRHYTHMIAS,
- **LOSS OF VASOCONSTRICTION**
  - AUTONOMIC NEUROPATHY, MEDICATION, DIFFUSIVE CLEARANCE, THERMAL ENERGY
- **PROCDURE RELATED**
  - DIALYSATE, AIR EMBOLISM, HEMOLYSIS

BLOOD VOLUME

- EXCESSIVE WEIGHT GAIN REQUIRING A HIGH UFR: **>1KG/HOUR IN AVERAGE SIZE PATIENT**
- HEMORRHAGE
- EMBOLISM
- PERICARDITIS
- INACCURATE DRY WEIGHT
- EATING ON DIALYSIS
- DIALYSIS TIME



RESPONSE TO HYPOVOLEMIA

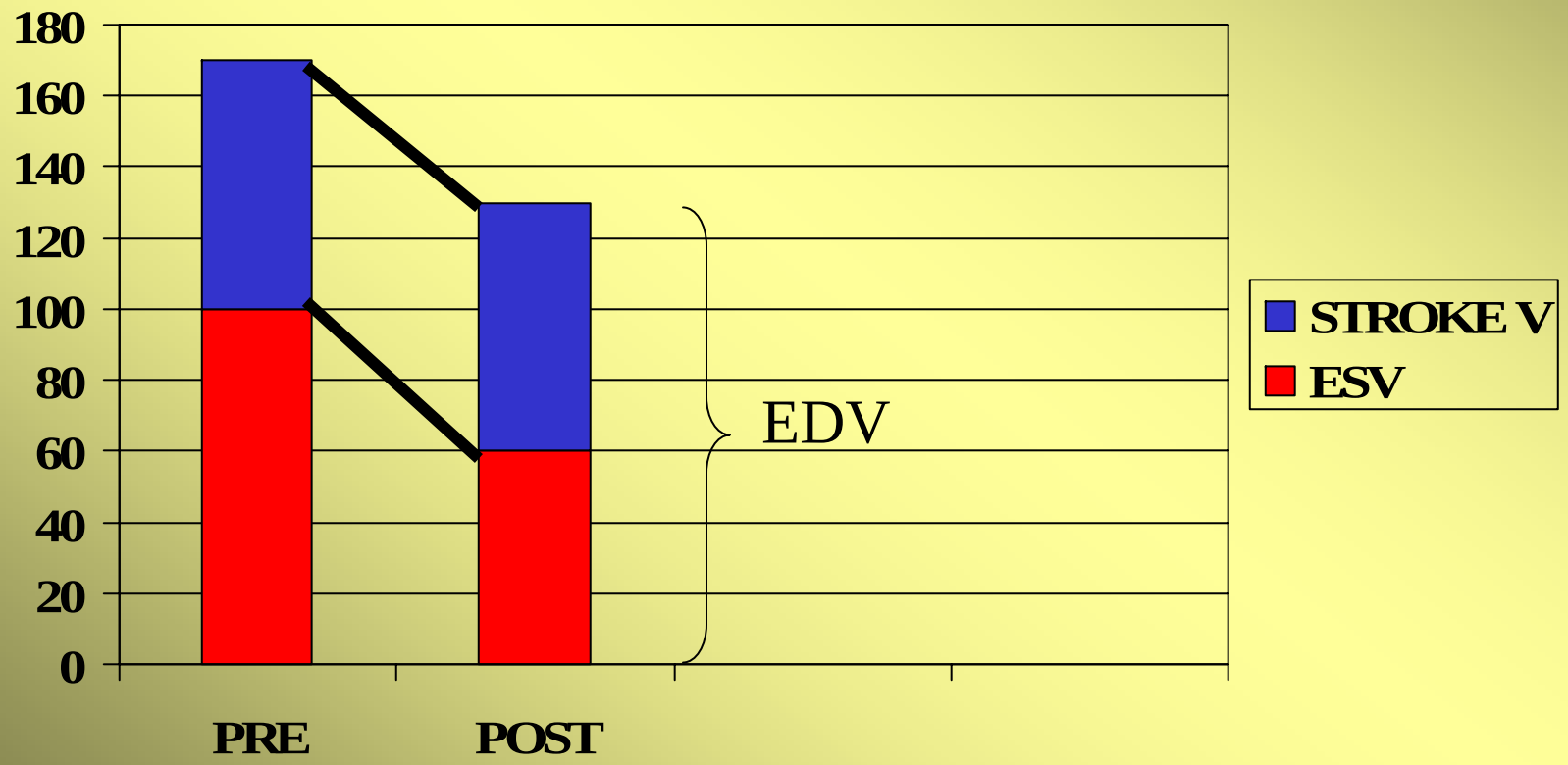
- INCREASE HEART RATE
- INCREASE MYOCARDIAL CONTRACTILITY SUPPORTING STROKE VOLUME
- INCREASE RESISTANCE
  - REDISTRIBUTE FLOW
  - EMPTY VENOUS CAPACITANCE BEDS
  - ACTIVATION OF HUMORAL RESPONSES: SYMPATHETIC NERVOUS SYSTEM AND RENIN ANGIOTENSIN SYSTEM

THE EFFECT OF HEMODIALYSIS ON CARDIAC CONTRACTILITY

J CLIN INVEST 71:377-384, 1983

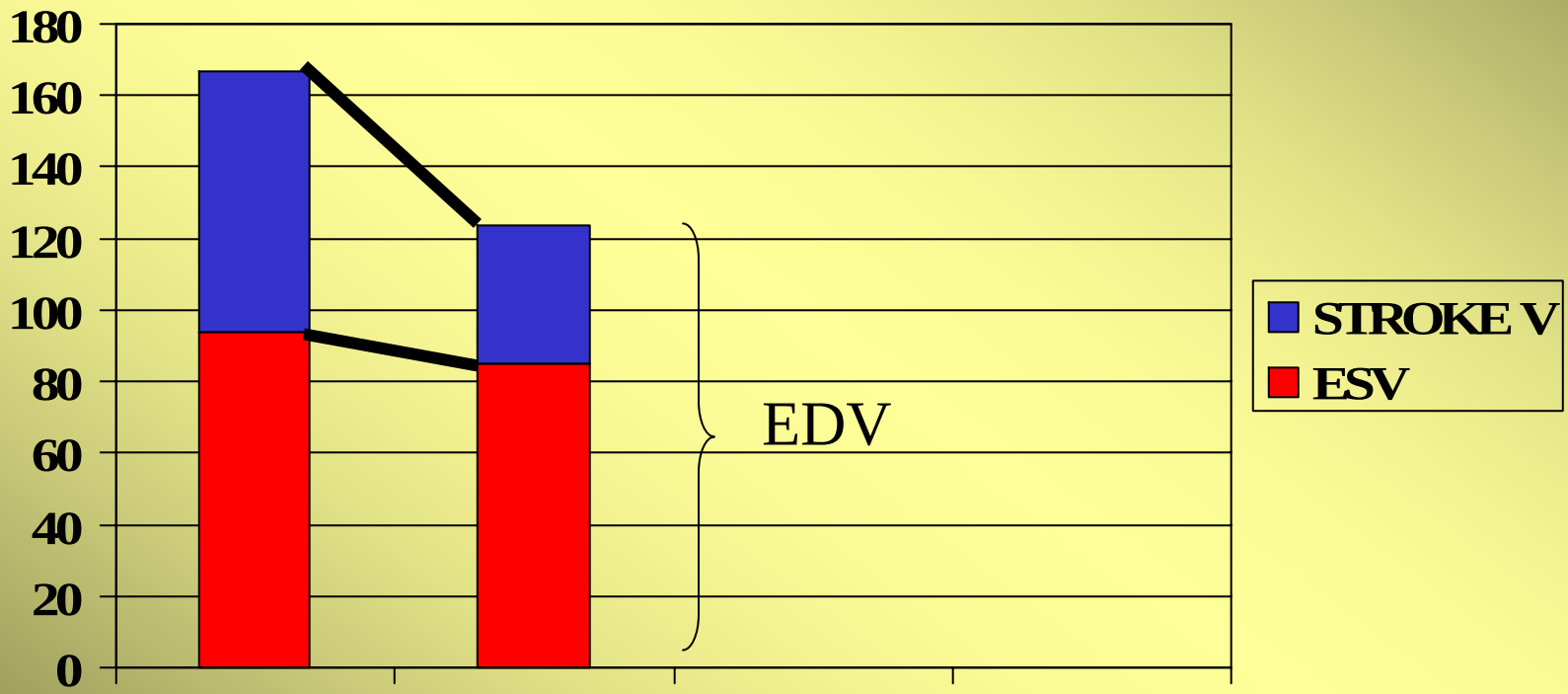
- n = 5 HD PATIENTS UDERGOING ALL STUDIES
- CUPROPHANE, ACETATE-BUFFERED DIALYSATE WITH 132 mEq/L SODIUM
- 3 MANUVERS
  - UF ONLY
  - REGULAR HD
  - ISOVOLEMIC HD
- PRE/POST HD ECHOCARDIOGRAMS UNDER BASELINE, LOW AND HIGH FILLING PRESSURES (NEGATIVE PRESSURE, TILT)

LV VOLUME: REGULAR DIALYSIS WITH ULTRAFILTRATION



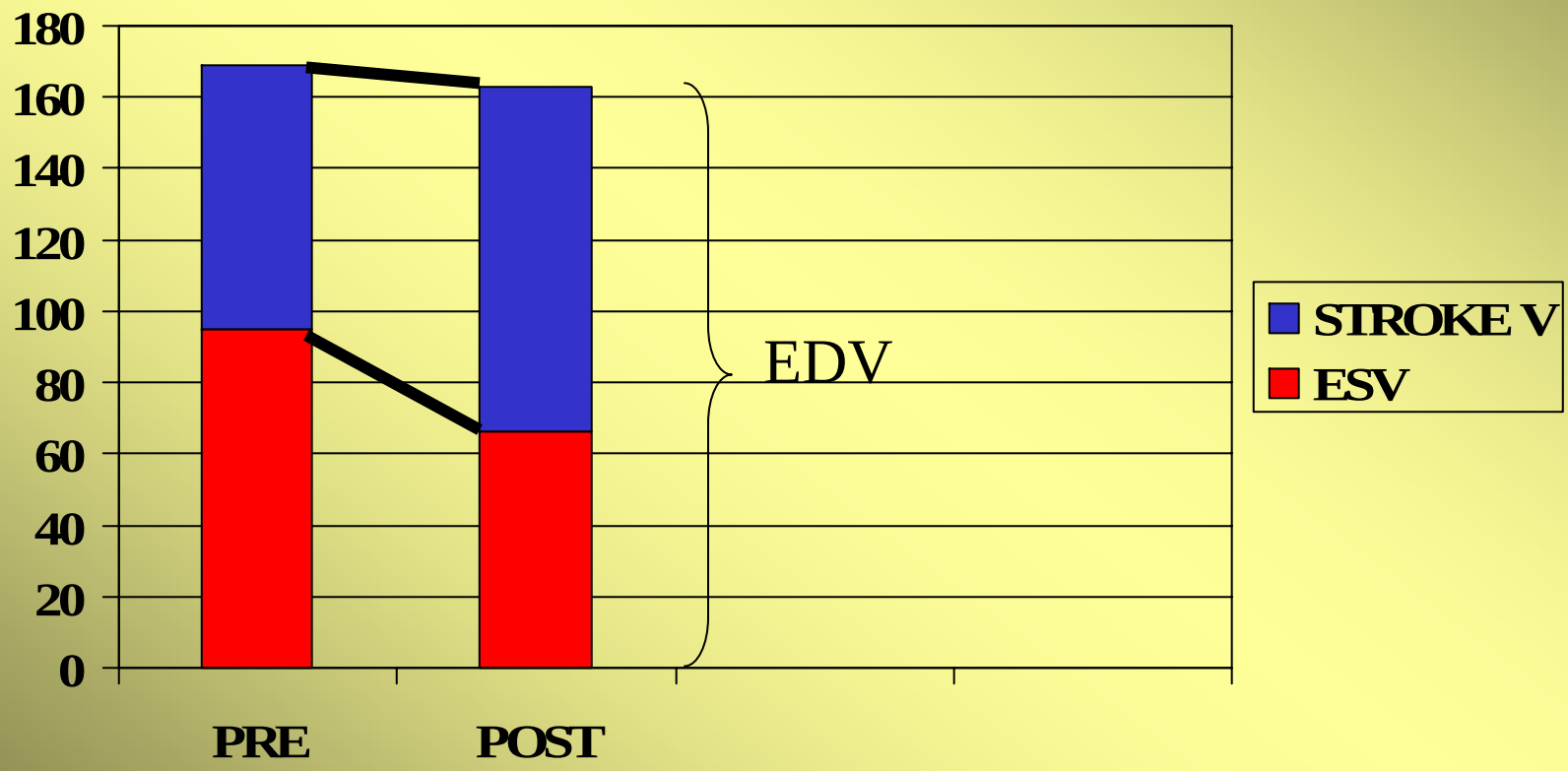
PRE	POST	
42	52	EF(%)
0.61	1.04	VCF

LV VOLUME: ULTRAFILTRATION ONLY



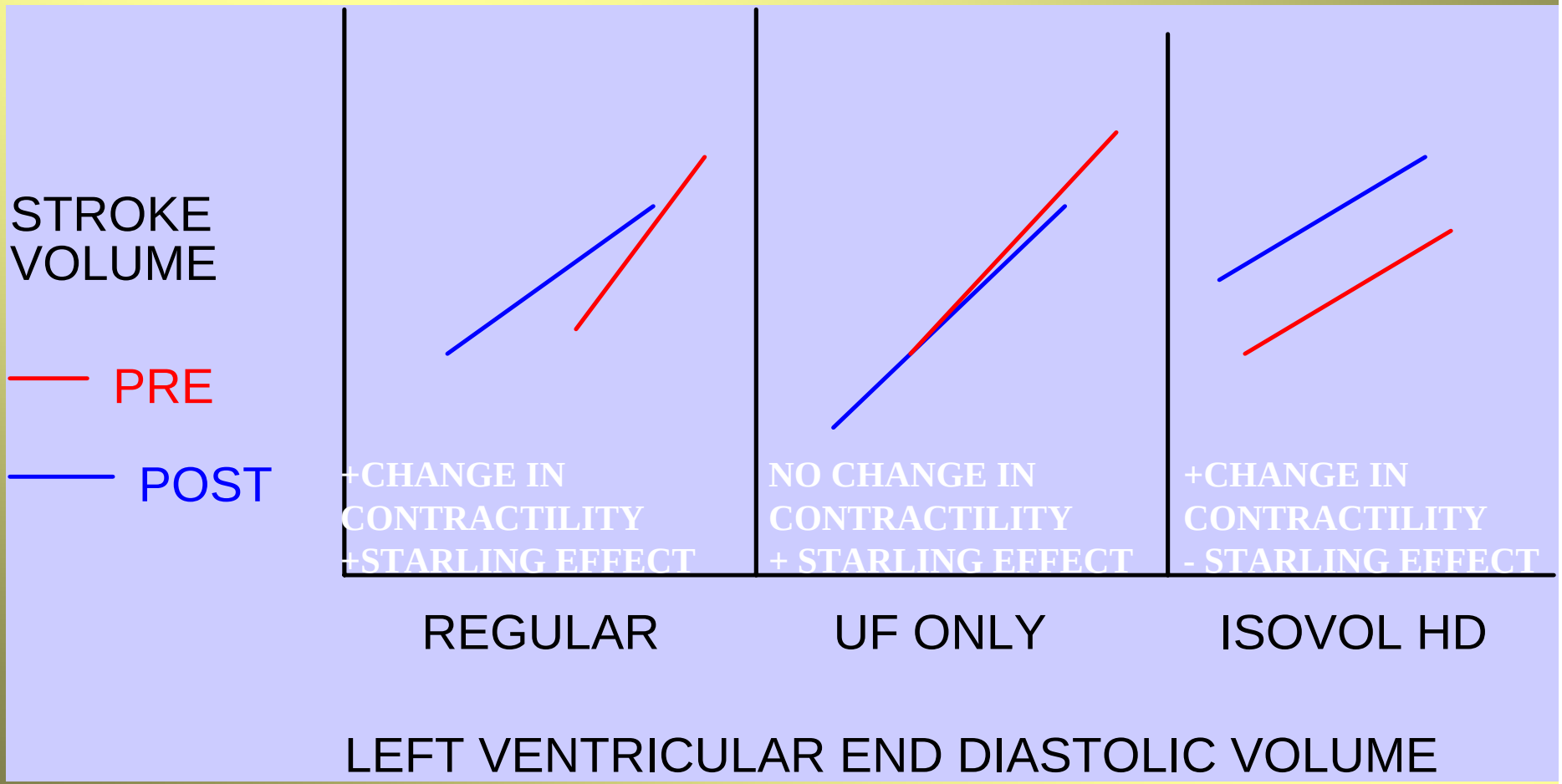
PRE	POST	
44	31	EF(%)
0.65	0.43	VCF

LV VOLUME: ISOVOLEMIC HEMODIALYSIS



PRE	POST	
44	59	EF(%)
0.64	1.26	VCF

LEFT VENTRICULAR FUNCTION CURVES



SUMMARY: THE EFFECT OF HEMODIALYSIS ON LV FUNCTION

	SV	ESV	EDV	EF	VCF	S-F
REG	⇔	↓	↓	↑	↑	YES
UF	↓	⇔	↓	↓	⇔	YES
IVHD	↑	↓	⇔	↑	↑	NO

CARDIAC FACTORS ASSOCIATED WITH HYPOTENSION

- SYSTOLIC DYSFUNCTION
- DIASTOLIC DYSFUNCTION
- INABILITY TO INCREASE HEART RATE
- ARRHYTHMIAS
- PERICARDITIS
- INFARCTION

LACK OF VASOCONSTRICTION

- ? DIFUSSION vs CONVECTION
- AUTONOMIC NEUROPATHY
- IMPAIRED HORMONAL RESPONSE
- DIALYSATE TEMPERATURE
- MEDICATION
- ANEMIA
- EATING DURING DIALYSIS

HEMODYNAMIC CHANGES DURING EXTRACORPOREAL THERAPIES

HEMODYNAMIC PARAMETERS	UF	HD	HF
ARTERIAL PRESSURE	↔	↔	↔
CARDIAC OUTPUT	↓	↔	↔
STROKE VOLUME	↓	↓	↔
HEART RATE	↔	↑	↔
SYSTEMIC RESISTANCE	↑	↔	↑

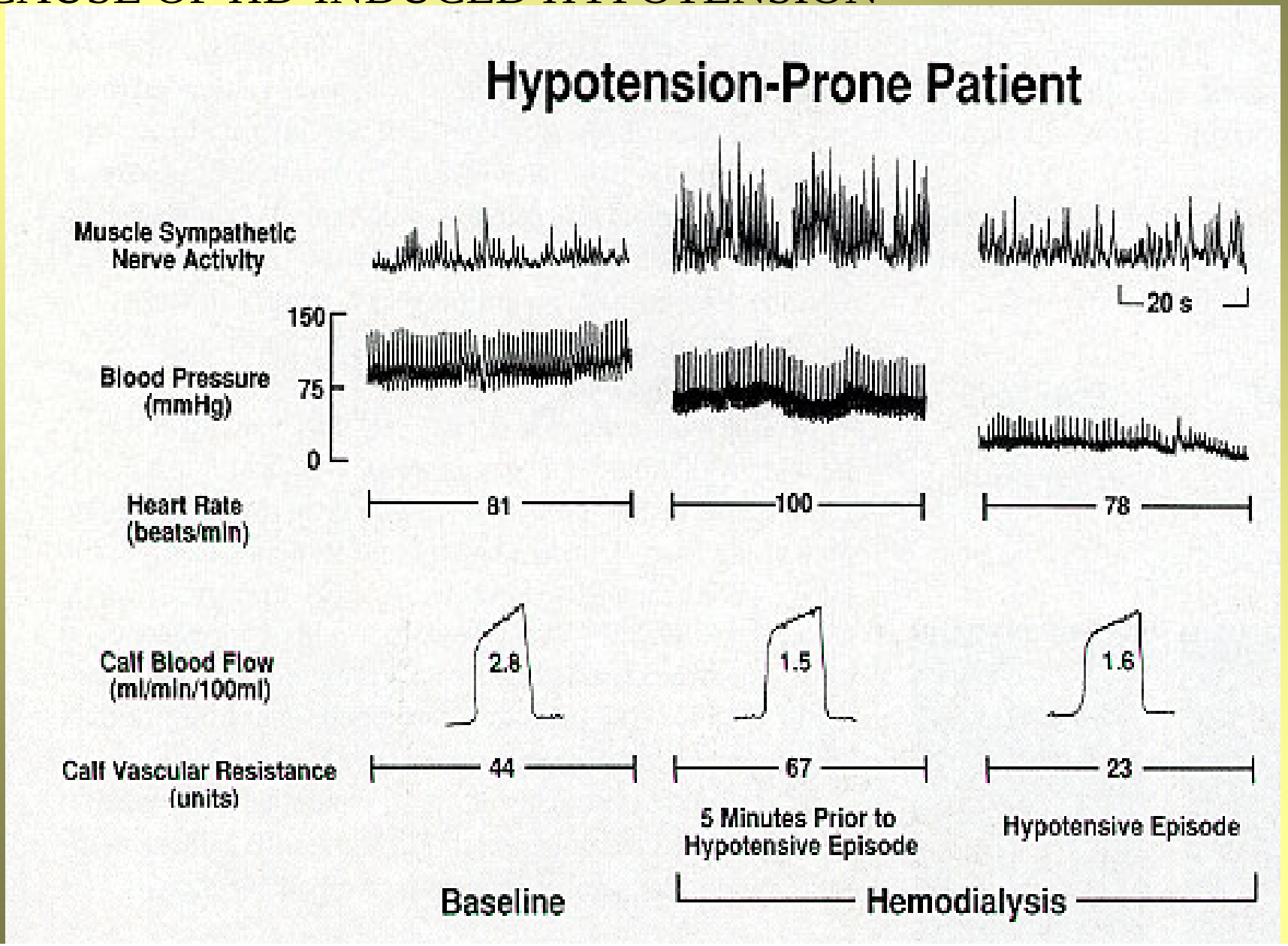
AUTONOMIC NEUROPATHY IN HEMODIALYSIS

- COMMON IN DIABETES
- AFFERENT LIMB IMPAIRED
- INCREASED TONIC SYMPATHETIC OUTPUT

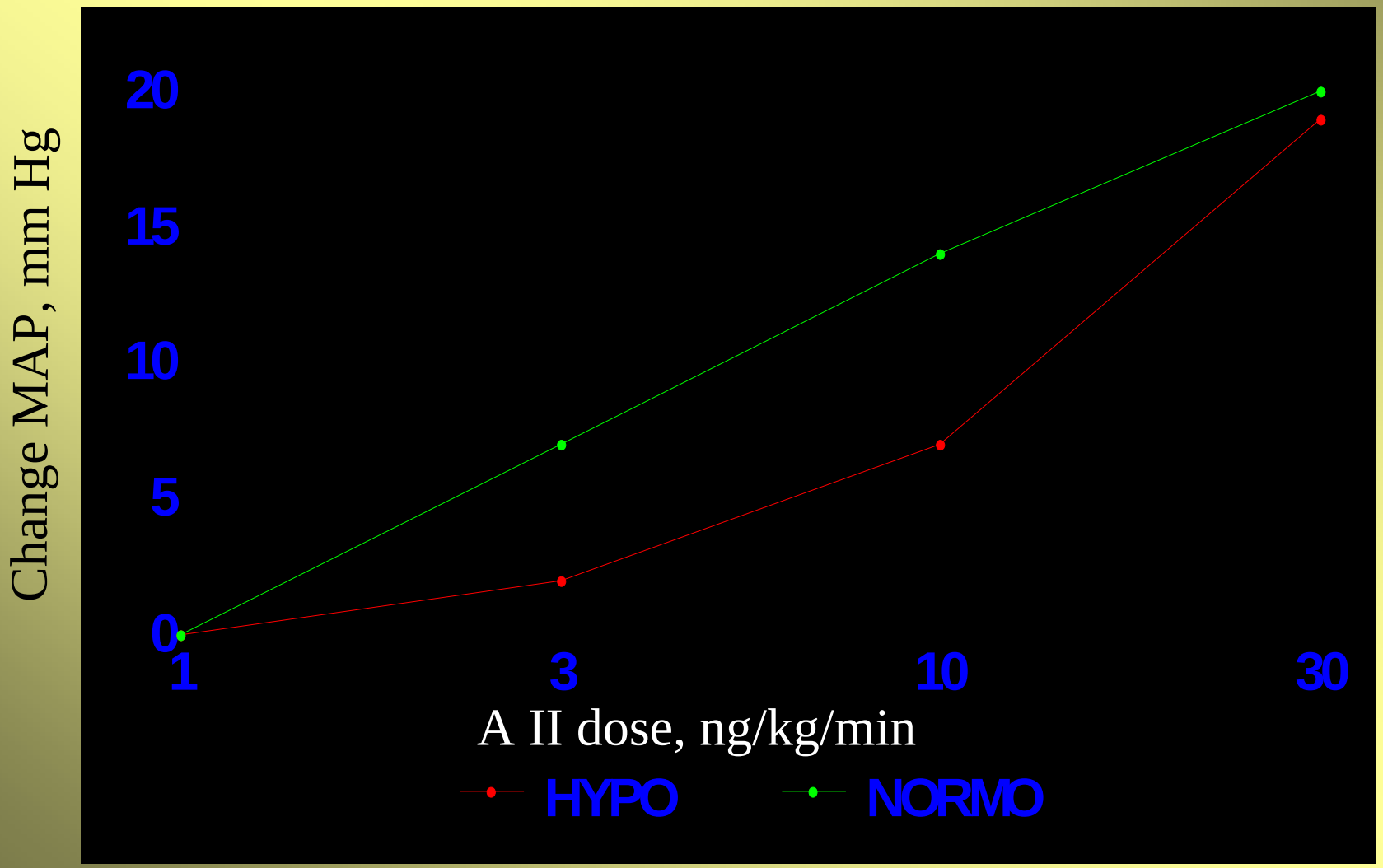
BUT

EFFERENT LIMB IMPAIRMENT AS WELL

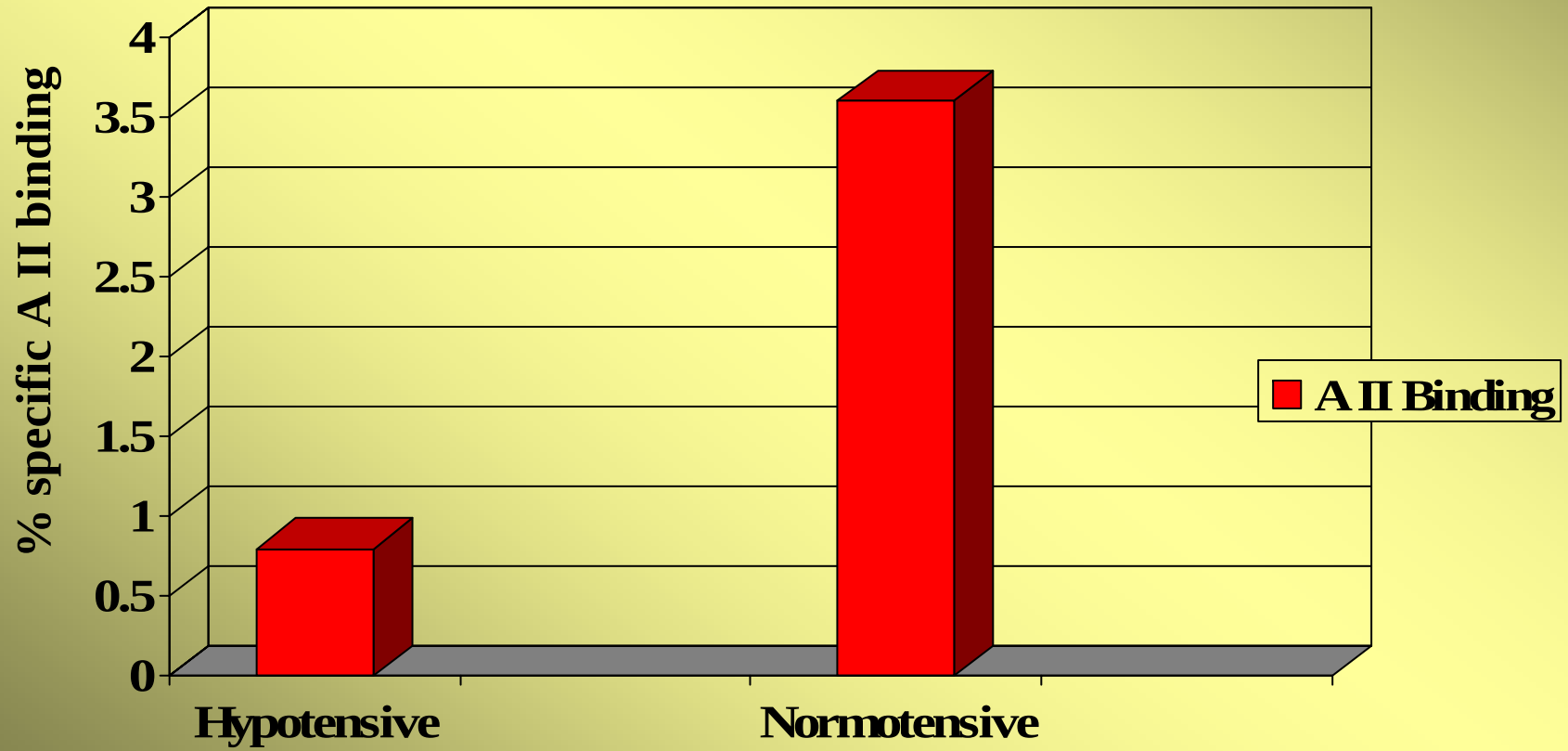
PARADOXICAL LOSS OF REFLEX VASOCONSTRITION AS CAUSE OF HD-INDUCED HYPOTENSION



RESPONSE OF HEMODIALYSIS PATIENTS TO GRADED AII INFUSION



SPECIFIC BINDING OF ANGIOTENSIN II TO PLATELETS IN HD PATIENTS



THE EFFECT OF ANEMIA AND ITS CORRECTION IN HD

ANEMIA

- INCREASED CARDIAC OUTPUT
- DECREASED BLOOD VISCOSITY
- **REDUCED PERIPHERAL VASCULAR RESISTANCE**

TRANSFUSION AND ERYTHROPOIETIN

- DECREASED CARDIAC OUTPUT
- INCREASED PERIPHERAL VASCULAR RESISTANCE AND BP
- INCREASED INTERDIALYTIC BP

VASCULAR CHANGES IN HD PATIENTS WITH EPO KI:38,1989

PARAMETERS	CONTROL	EPO
LAD (cm)	3.43 +/- 0.33	3.22 +/- 0.3
HR	76.1 +/- 8	70 +/-10
LVMI (g/m^2)	133 +/- 30.8	109.8 +/- 30.6
CI ($L/min/m^2$)	4175 +/- 700	3635 +/- 444
TPR	1480 +/- 162	1943 +/- 250

POSTPRANDIAL HYPOTENSION: IMPAIRED VASOCONSTRICTION

- FOOD INGESTION
  - ◆DECREASE IN PERIPHERAL VASCULAR RESISTANCE
  - ◆WORSENED BY AUTONOMIC DYSFUNCTION

    &

  - ◆INCREASE IN SPLANCHNIC BLOOD FLOW
    - ✡DECREASED VENOUS RETURN

DIALYSATE CONSIDERATIONS

- BUFFER
- OSMOLARITY/SODIUM
- CALCIUM AND MAGNESIUM CONCENTRATION
- TEMPERATURE

DIALYSATE CONSIDERATIONS

- **BUFFER**
- **OSMOLARITY/SODIUM**
- **CALCIUM AND MAGNESIUM CONCENTRATION**
- **TEMPERATURE**

BUFFER

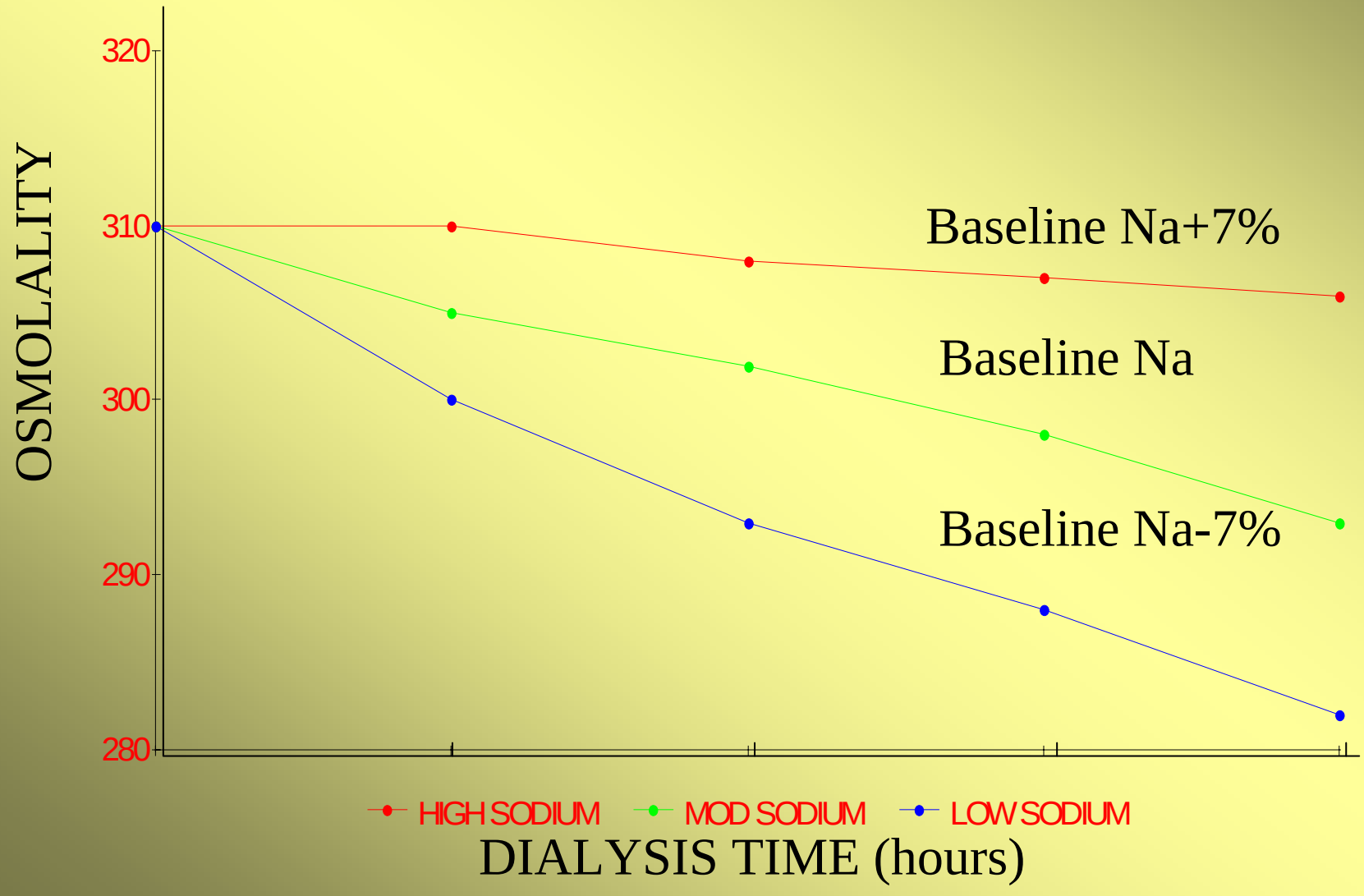
- ACETATE vs BICARBONATE
  - OF HISTORICAL NOTE ONLY ⇨ UNIVERSAL USE OF BICARBONATE-BASED DIALYSATE
- ACETATE
  - VASODILATOR
  - MYOCARDIAL DEPRESSANT
  - 200 mM/hr MAXIMUM RATE OF METABOLISM
  - MUSCLE MASS DEPENDENT

DIALYSATE CONSIDERATIONS

- BUFFER
- OSMOLARITY/SODIUM
- CALCIUM AND MAGNESIUM CONCENTRATION
- TEMPERATURE

Vanderbilt University Medical Center

EFFECT OF DIALYSIS SODIUM ON SERUM OSMOLALITY



DIALYSATE SODIUM AND FLUID COMPARTMENTS

- DIALYSATE SODIUM ~ SERUM SODIUM:

SOURCE OF ULTRAFILTRATE IS FROM THE ECF COMPARTMENT

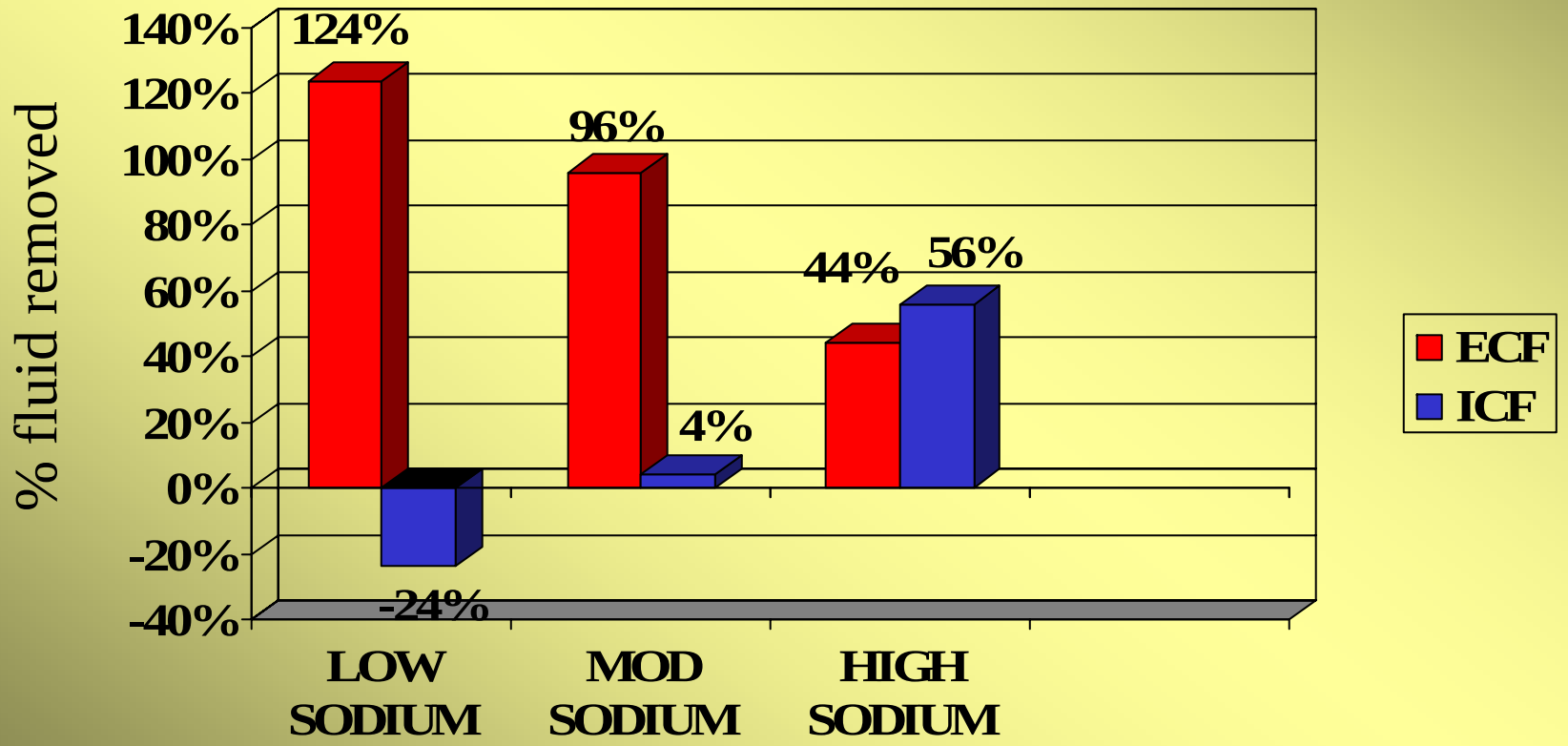
- DIALYSATE SODIUM < SERUM SODIUM:

SOURCE OF ULTRAFILTRATE IS FROM THE ECF COMPARTMENT *AND* ECF ALSO MOVES INTO THE ICF COMPARTMENT (INTERNAL PHLEBOTOMY)

- DIALYSATE SODIUM > SERUM SODIUM:

SOURCE OF ULTRAFILTRATE IS FROM ECF AND ICF COMPARTMENTS

DIALYSATE SODIUM CONCENTRATION AND COMPARTMENTAL FLUID LOSS



CHRONIC EFFICACY OF HIGH SODIUM DYALYSATE

AJKD 2:349-353, 1982

- n = 10
- Double blind, crossover
- [Na]: 144 mEq/L vs 132 mEq/L
- OUTCOME
  - DECREASED HYPOTENSION
  - INCREASED INTERDIALYTIC WEIGHT GAINS
  - INCREASED VOLUME REMOVED DURING DIALYSIS

HIGH SODIUM DIALYSATE OR BUFFER:WHICH IS MORE IMPORTANT?

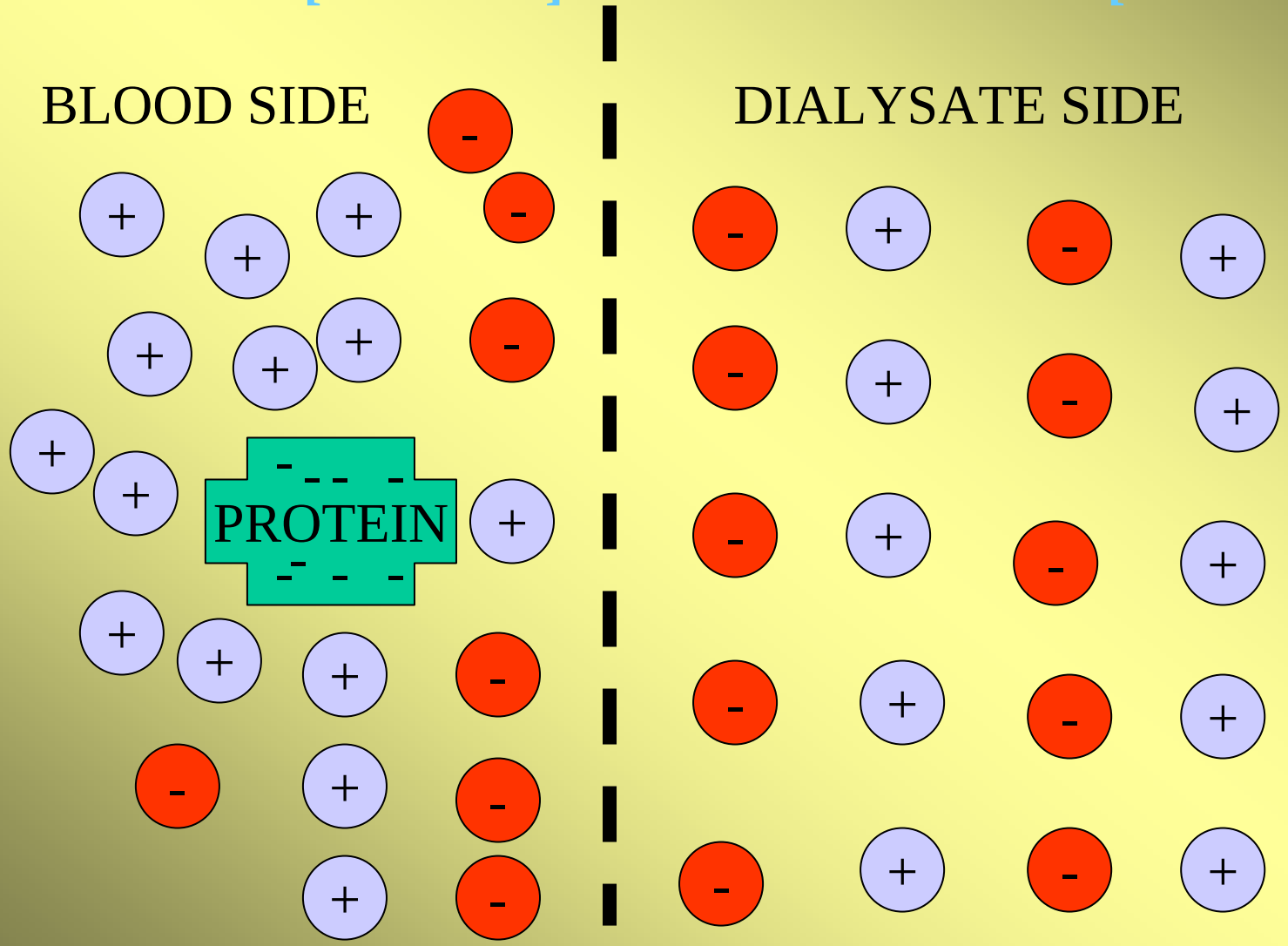
- HIGH SODIUM DIALYSATE BUFFERED WITH ACETATE RESULTS IN INCREASED INTERDIALYTIC WEIGHT GAINS, BUT ALLOWS GREATER UFR WITHOUT HYPOTENSION
- AT THE SAME SODIUM CONCENTRATION, BICARBONATE RESULTS IN LESS HYPOTENSION
- **SODIUM IS OF GREATER IMPORTANCE**

CONCERNS INVOLVING HIGH DIALYSATE SODIUM CONCENTRATIONS

- TRADE-OFF HYPOTHESIS: A CHANGE INTRODUCED TO CORRECT ONE ABNORMALITY MAY RESULT IN OTHER PATHOPHYSIOLOGIC CONSEQUENCES: MAINTAINING [Ca^{+}] LEADS TO ROD
- TRADE-OFFS IN ARTIFICIAL PHYSIOLOGY
  - ALUMINUM AND CALCIUM P-BINDERS
  - **DIALYSATE SODIUM**
  - **? DIALYSATE CALCIUM**

CONSEQUENCES OF THE DONNAN EQUILIBRIUM: $(Na \times CL)_{blood} = (Na \times Cl)_{dialysate}$

BLOOD SIDE [CATION] > DIALYSATE SIDE [CATION]



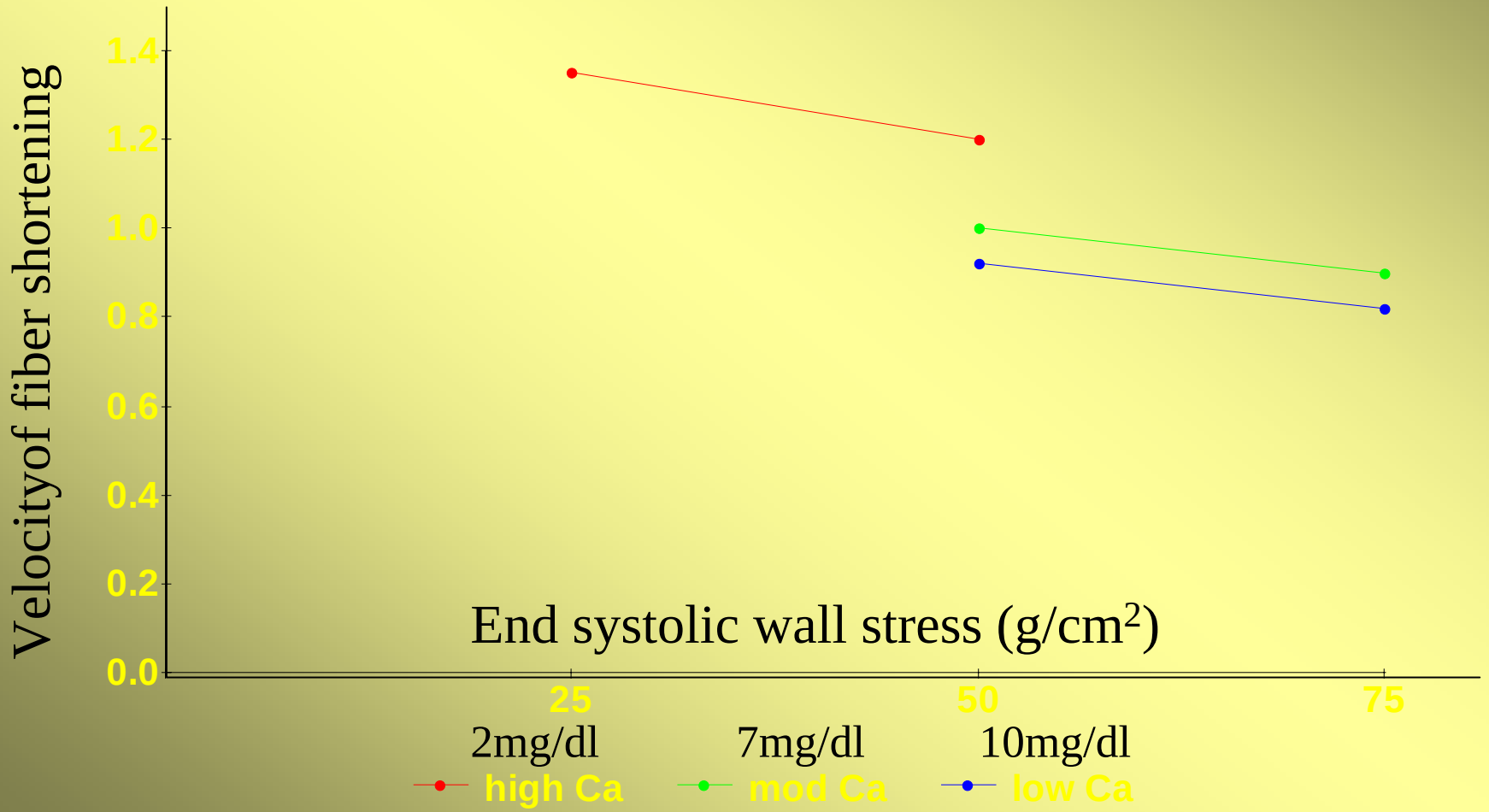
DIALYSATE SODIUM: ISSUES

- [DIALYSATE SODIUM] TO [SERUM SODIUM] GRADIENT AT WHICH SODIUM TRANSFER EXCHANGE IS PREVENTED: -3 mEq/L
- HIGH SODIUM AND ISONATREMIC DIALYSATE HAVE THE POTENTIAL TO INCREASE EXCHANGEABLE SODIUM POOL
- POTENTIAL CONSEQUENCES OF INCREASED EXCHANGEABLE SODIUM
  - THIRST
  - INCREASED INTERDIALYTIC WEIGHT GAIN
  - HYPERTENSION

DIALYSATE CONSIDERATIONS

- **BUFFER**
- **OSMOLARITY/SODIUM**
- **CALCIUM AND MAGNESIUM CONCENTRATION**
- **TEMPERATURE**

EFFECTS OF CALCIUM ON CARDIAC CONTRACTILITY



DIALYSATE MAGNESIUM AND HYPOTENSION

MAGNESIUM CONCENTRATION	CHANGE IN MAP (mm Hg)	HYPOTENSIVE EPISODES (%)
LOW Mg (0.38 mM)	-16 +/- 4	28.5
HIGH Mg (0.75 mM)	-28 +/- 4	61.9

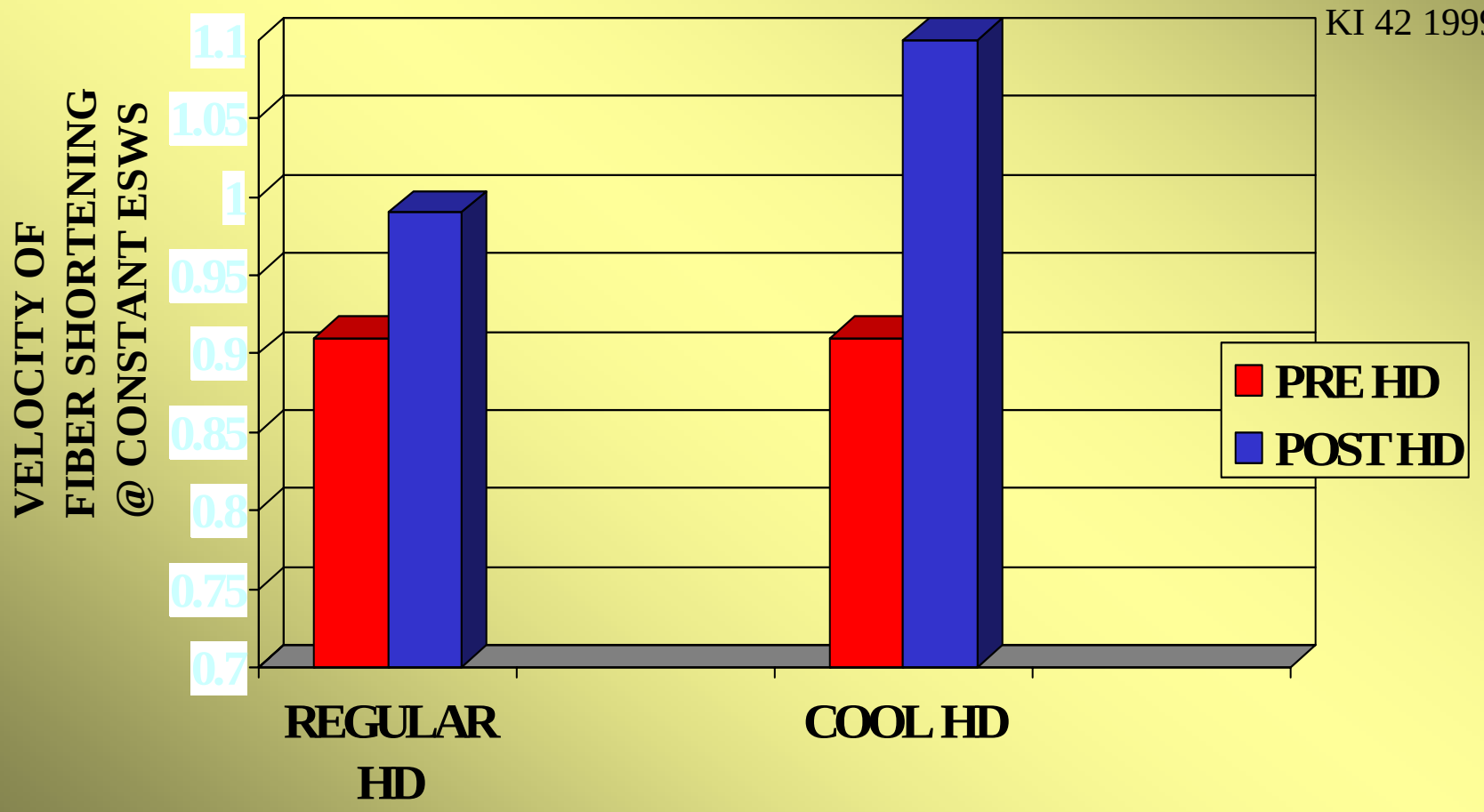
CONCERNS WITH CALCIUM AND MAGNESIUM

- WIDESPREAD USE OF CALCIUM SALTS TO CONTROL PHOSPHORUS
  - HYPERCALCEMIA ~30%
  - CALCIPHYLAXIS
  - ADYNAMIC BONE DISEASE
- HYPOMAGNESEMIA
  - CRAMPS

DIALYSATE CONSIDERATIONS

- **BUFFER**
- **OSMOLARITY/SODIUM**
- **CALCIUM AND MAGNESIUM CONCENTRATION**
- **TEMPERATURE**

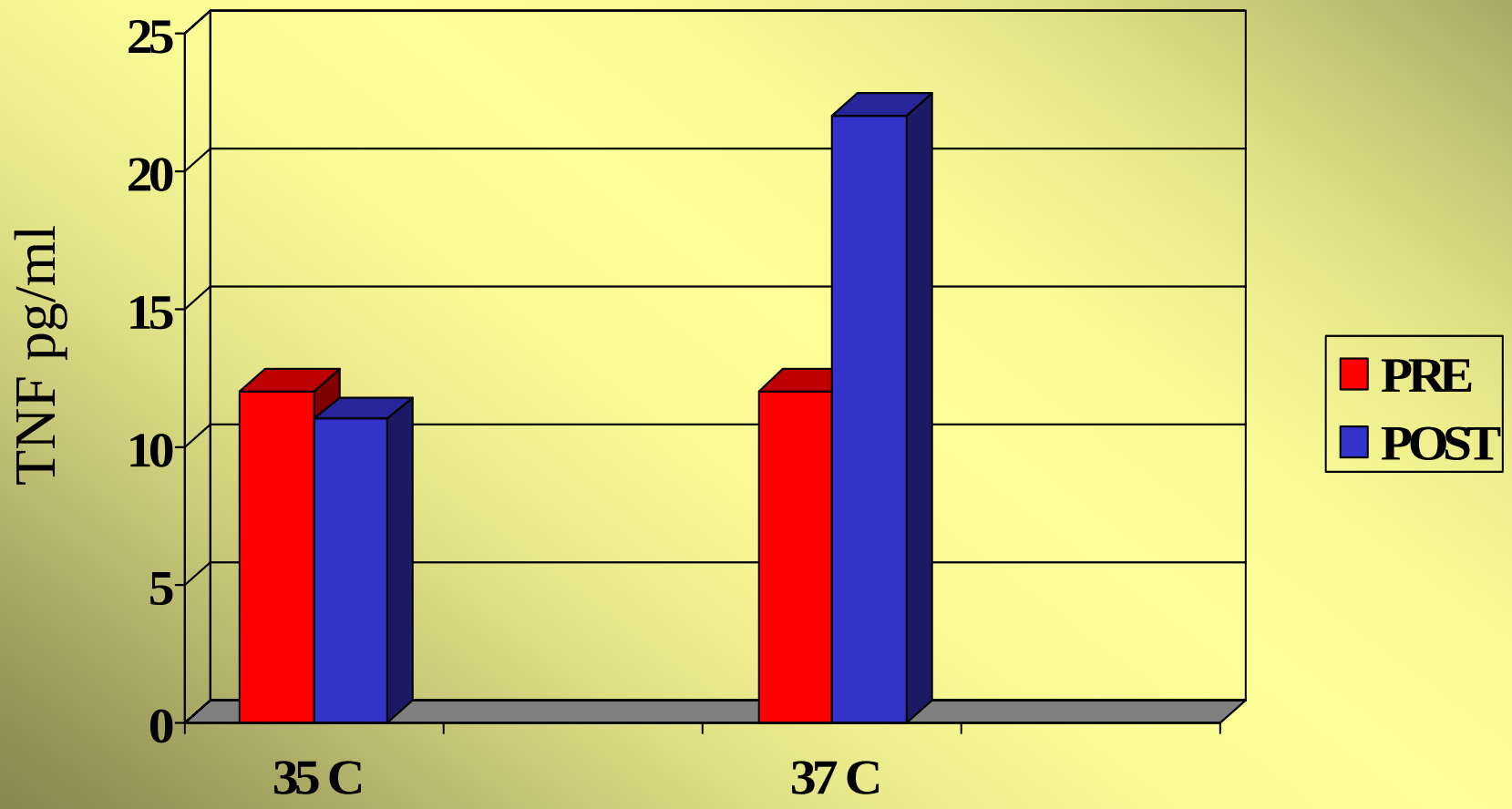
DIALYSATE TEMPERATURE AND CARDIAC CONTRATILITY



THERMAL ENERGY TRANSFER AND VASCULAR TONE JASN 2000

DIALYTIC MODALITY	CORE TEMPERATURE	VASCULAR ACTIVITY	VENOUS TONE
UF	DECREASE	INCREASE	INCREASE
HD_{37}	INCREASE	NO CHANGE	DECREASE
HD_{35}	DECREASE	INCREASE	INCREASE
$HD_{UF\ ET}$	NO CHANGE	INCREASE	INCREASE

DIALYSATE TEMPERATURE AND CYTOKINE GENERATION



TEMPERATURE AND BP DURING HD

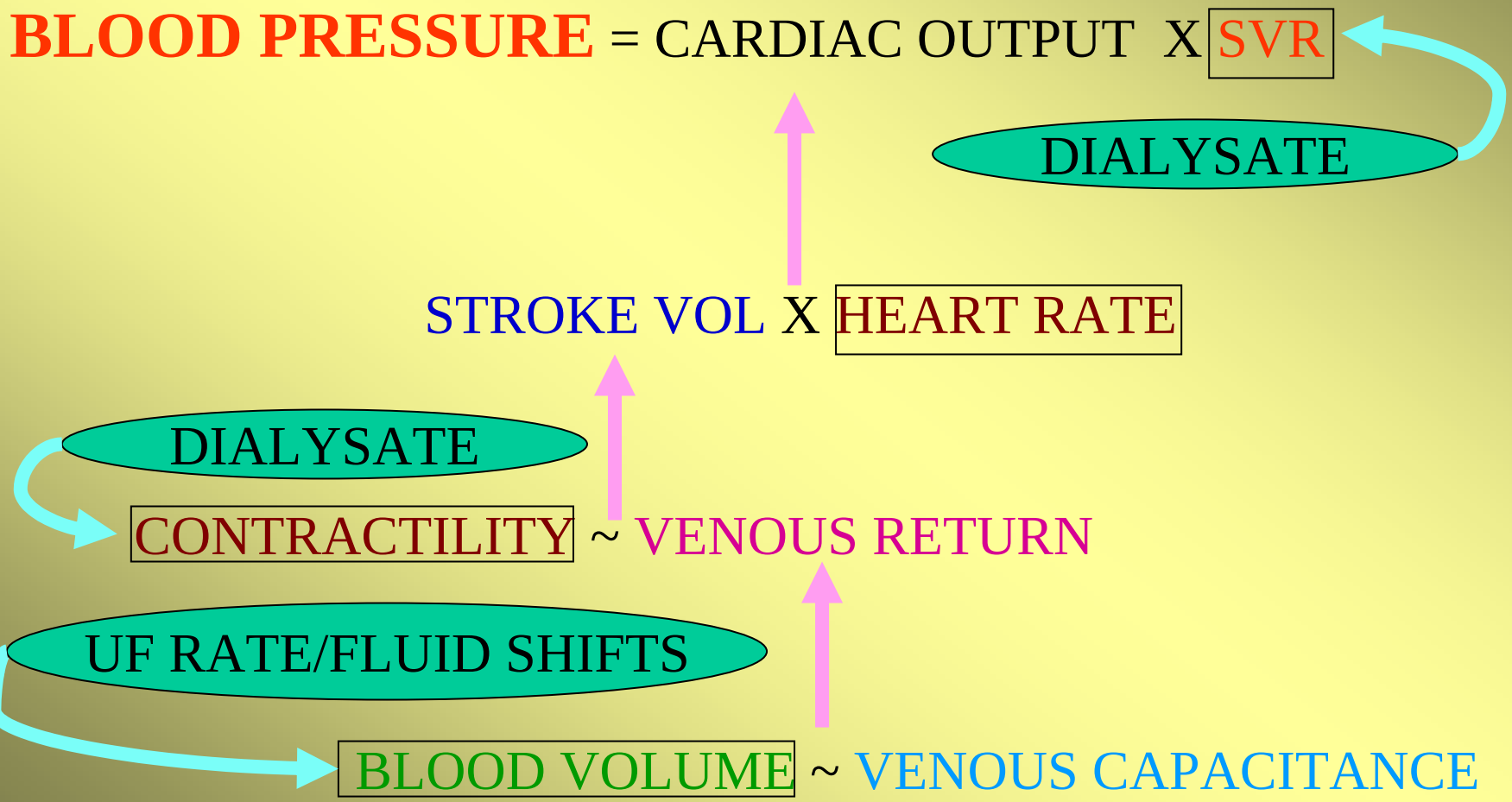
n = 8 HYPOTENSION PRONE HD PATIENTS

PARAMETER	37C	35C
SYSTOLIC BP (mmHg)	145	138
WEIGHT LOSS (KG)	1.5	1.9
HYPOTENSIVE EPISODES (%)	45	30

THE EFFECTS OF HEMODIALYSIS AND CHANGES IN THERMAL ENERGY

- ISOTHERMIC HD: 6% of INTRADIALYTIC ENERGY EXPENDITURE IS LOST FOR EACH 1% WEIGHT ULTRAFILTERED AJKD 2000
- COOL DIALYSATE: LESS HYPOTENSION
  - **THE MAIN REASON FOR SUPERIOR HEMODYNAMIC STABILITY OF ISOLATED ULTRAFILTRATION**
    - INCREASE IN MYOCARDIAL CONTRACTILITY
    - INCREASED VASCULAR TONE
- MIXED ACCEPTANCE BY PATIENTS

DETERMINANTS OF BLOOD PRESSURE AND THE EFFECTS OF DIALYSIS



INTERVENTIONS

- EVALUATE DRY WEIGHT
- TREAT REVERSIBLE CAUSES
- BELLS, WHISTLES AND GIZMOS
- MEDICATIONS

INTERVENTIONS

- ***EVALUATE DRY WEIGHT***
  - **LIMIT WEIGHT GAINS**
- ***TREAT REVERSIBLE CAUSES***
  - **HYPOTENSIVE MEDICATION**
  - **CONSIDER INCREASING DIALYSIS TIME**
    - **TASSIN/NOCTURNAL HD EXPERIENCE**
- BELLS, WHISTLES AND GIZMOS
- MEDICATIONS

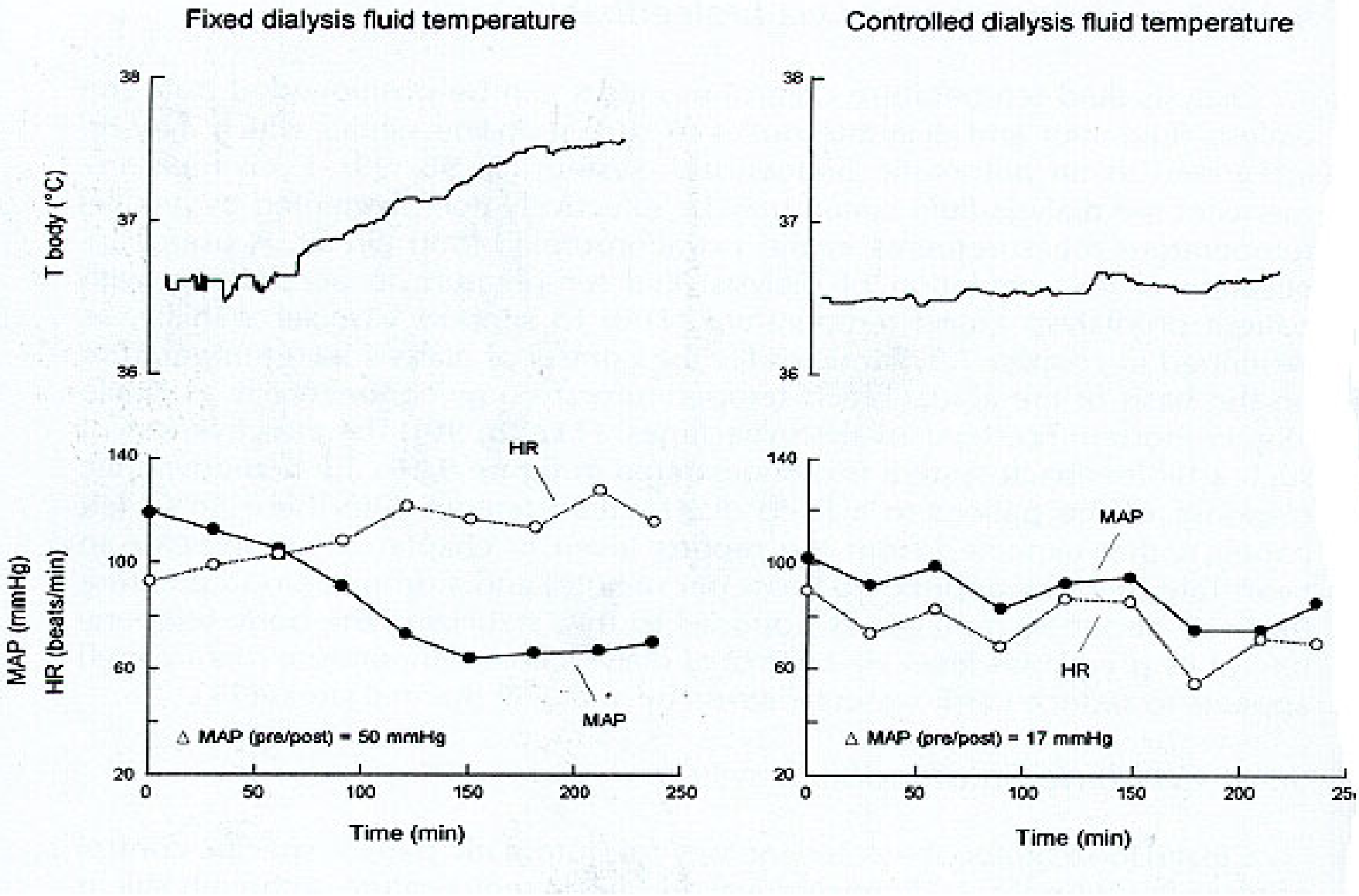
INTERVENTIONS

- EVALUATE DRY WEIGHT
- TREAT REVERSIBLE CAUSES
- ***BELLS, WHISTLES AND GIZMOS***
- MEDICATIONS

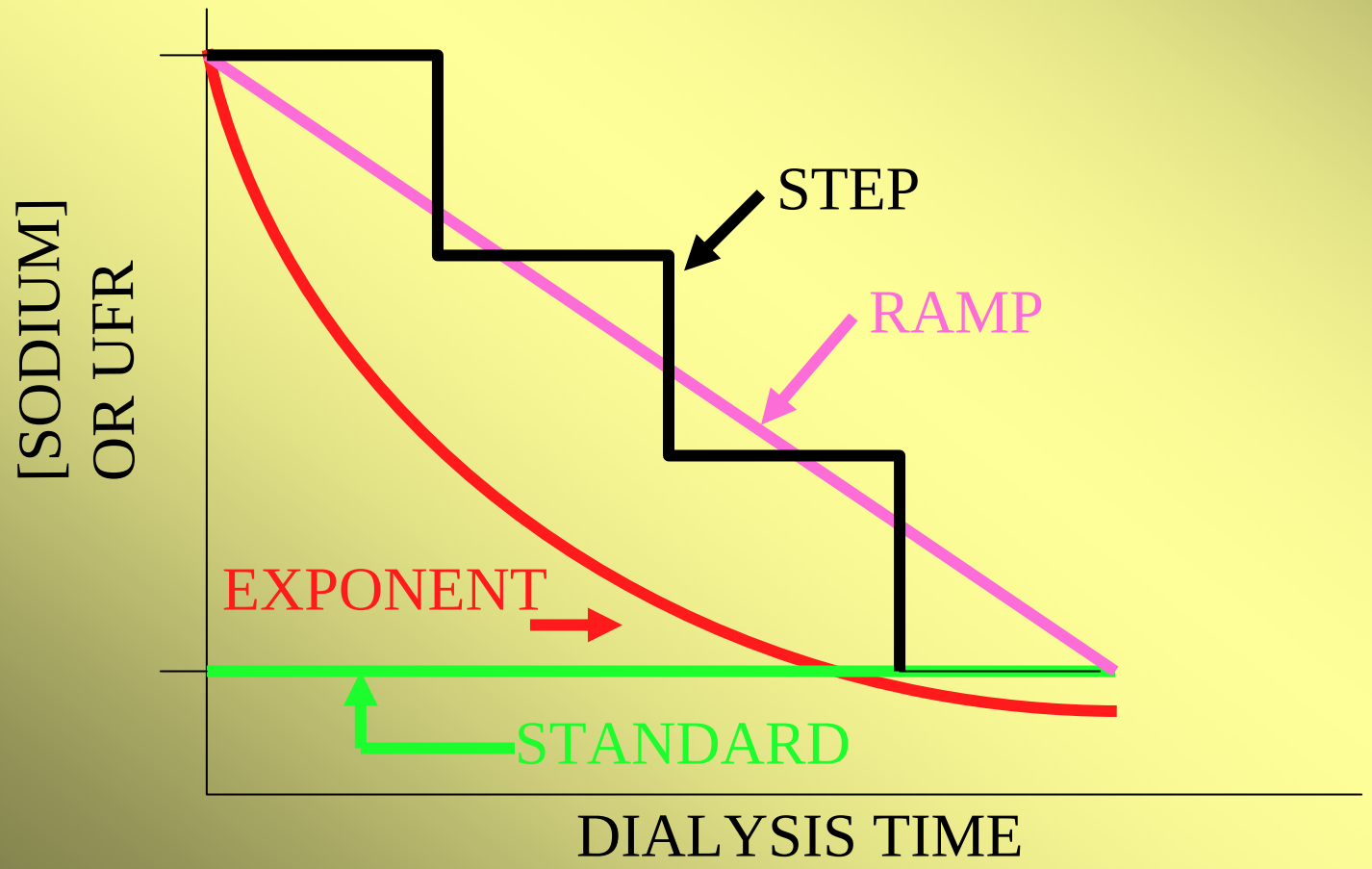
AIDS TO PREVENT HYPOTENSION DURING HD

- VOLUMETRIC MACHINES
- VARIABLE DIALYSATE TEMPERATURE
- SODIUM MODELING
- VARIABLE ULTRAFILTRATION
- ON-LINE HEMOGLOBIN MEASUREMENT
- HEMODYNAMIC MONITORING/IVC ECHO
- PRESSORS, ?ALBUMIN
- INCREASED DIALYSIS TIME

HEMODYNAMIC EFFECTS OF DIALYSATE TEMPERATURE CONTROL



SODIUM MODELING AND ULTRAFILTRATION PATTERNS



SYMPTOMS DURING STEADY vs RAMP SODIUM PATTERN

	HYPOTENSION	LOWEST BP	CRAMPS
CONSTANT	1.3	114/66	0.9
BOTH RAMP PATTERNS	0.7	123/69	0.5

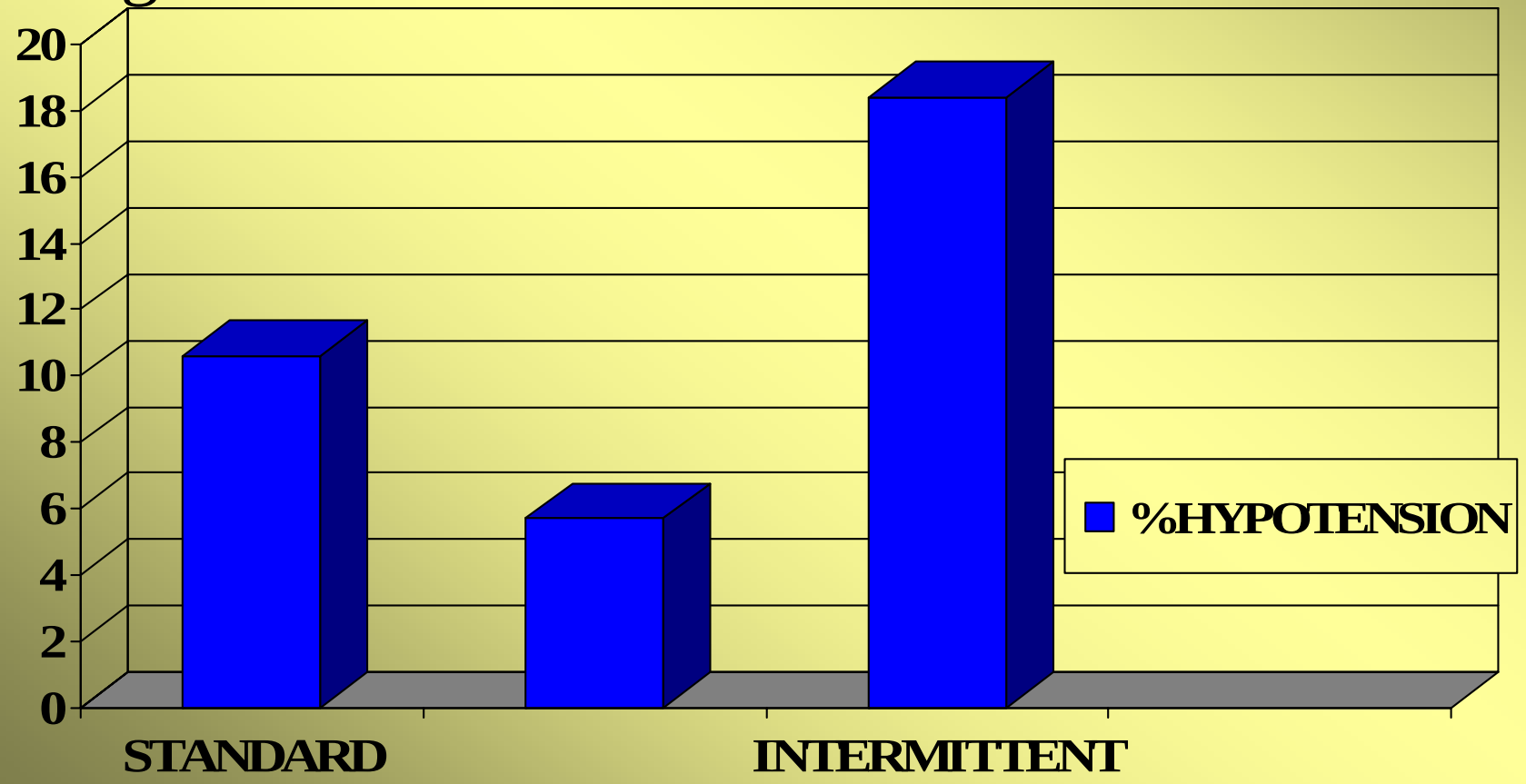
SYMPTOMS DURING STEADY vs RAMP SODIUM PATTERN

- 22% (5 PATIENTS) REPORTED MARKED IMPROVEMENT
- SIGNIFICANTLY MORE THIRST AND FATIGUE DURING RAMPING
- INTERDIALYTIC WEIGHT GAIN 5.1% (RAMPING) vs 4.4% (STEADY); $p<0.0001$
- PREDIALYSIS BP: 152/81 (RAMPING) vs 143/79 (STEADY); $p<0.001$

VARIABLE ULTRAFILTRATION

AJKD 36:115-123,2000

- n = 53 Patients in 188 treatments
- Constant UF vs Ramp UF vs Intermittent High UF

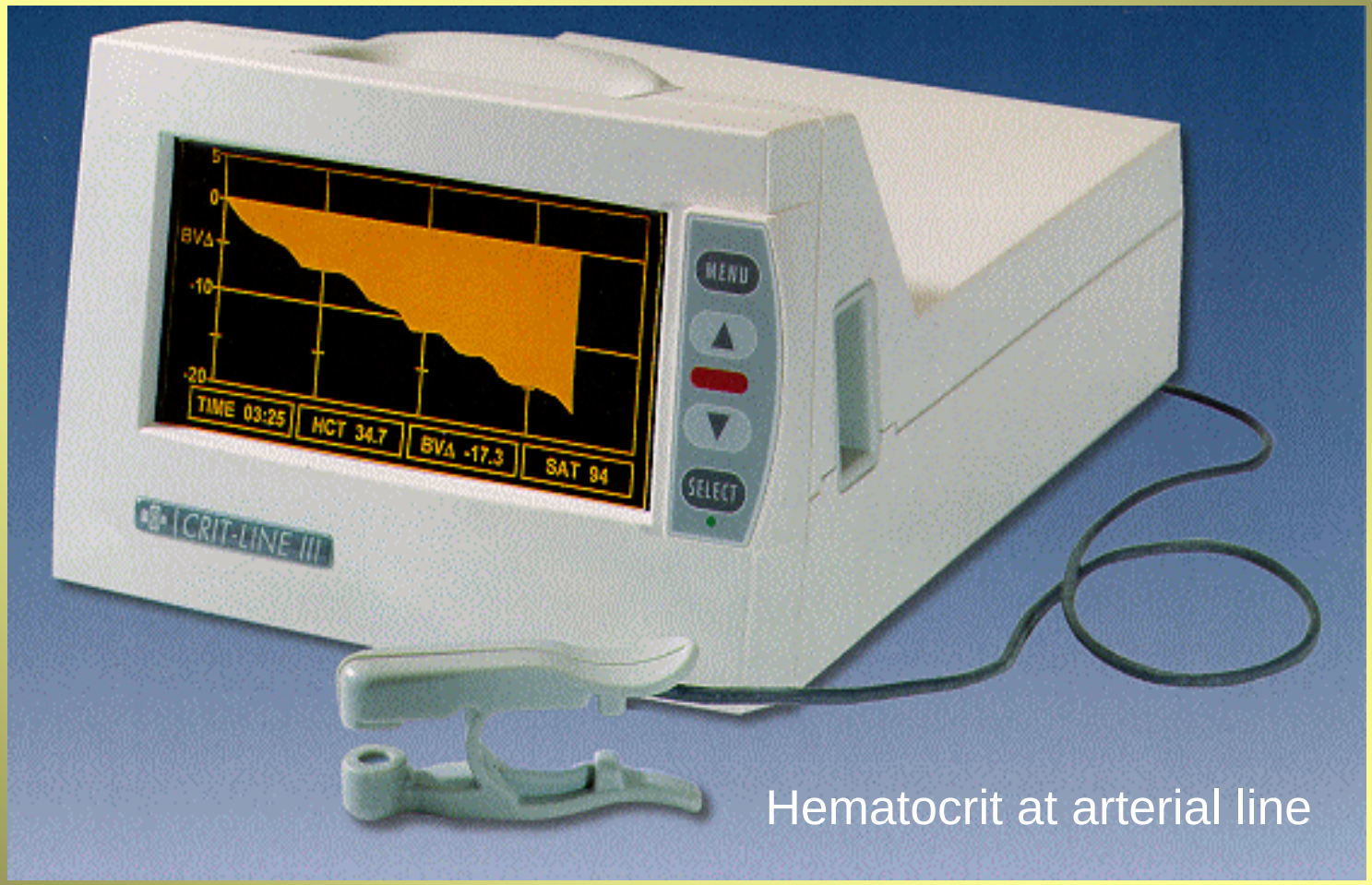


HEMATOCRIT MONITORS

MEASUREMENT OF BLOOD VOLUME: ASSESSMENT OF EDW AND PREVENTION OF HYPOTENSION

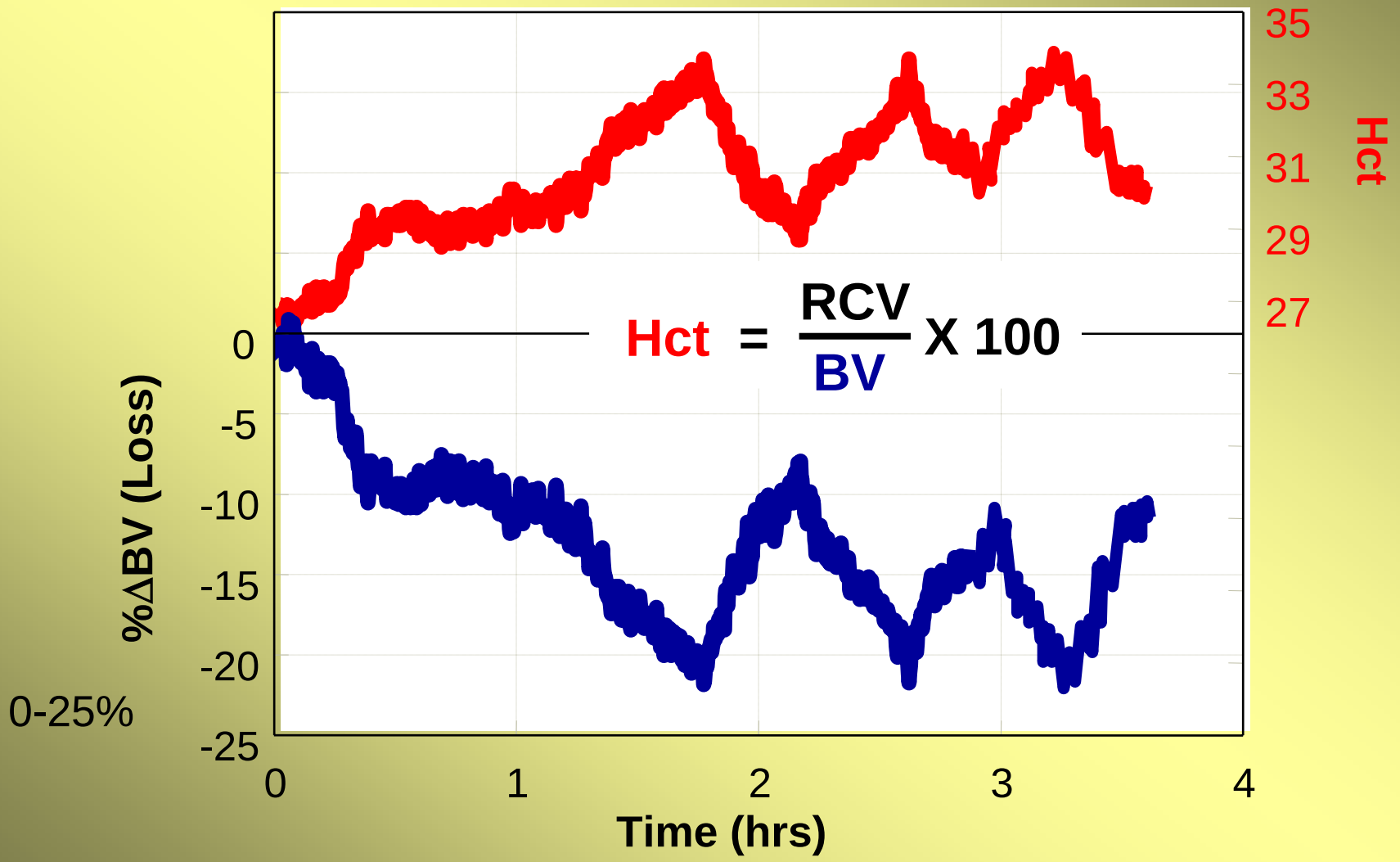
CritLine Monitor

pro



Hematocrit at arterial line

Changes in Hct & RELATIVE Blood Volume during Hemodialysis

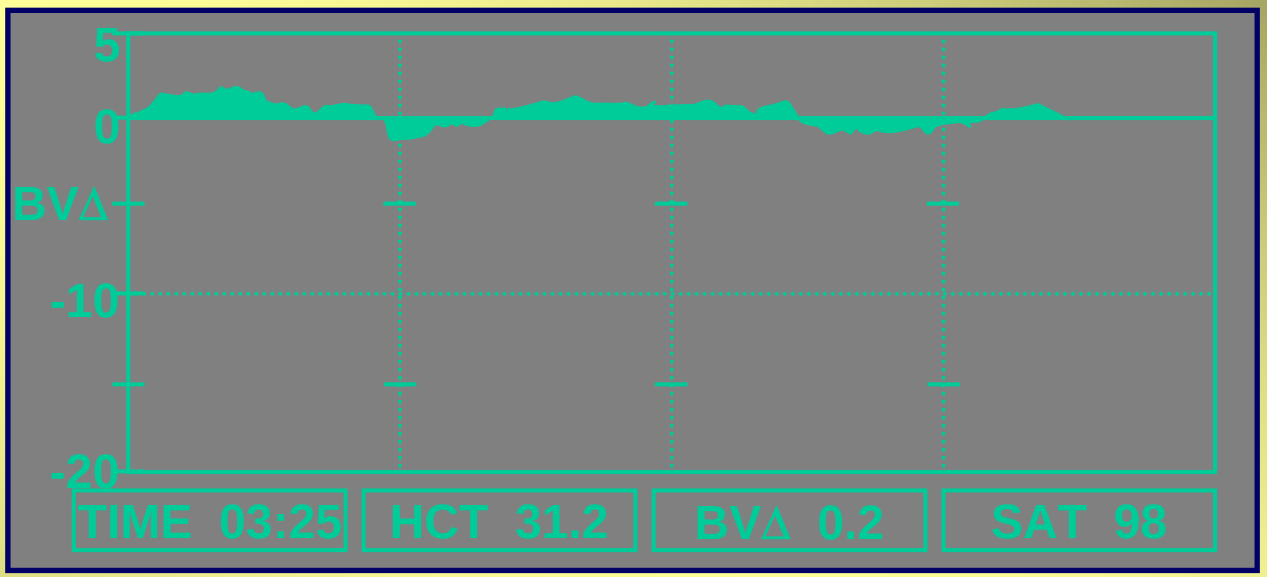


Caveats: Unstable RBC mass; fistula recirculation

BLOOD VOLUME MONITORS

How to use Volume Monitor
to assess Dry Weight?

Stable Plasma Volume



Plasma Refilling Rate (PRR) = Ultrafiltration Rate (UFR)

Common Interpretation:

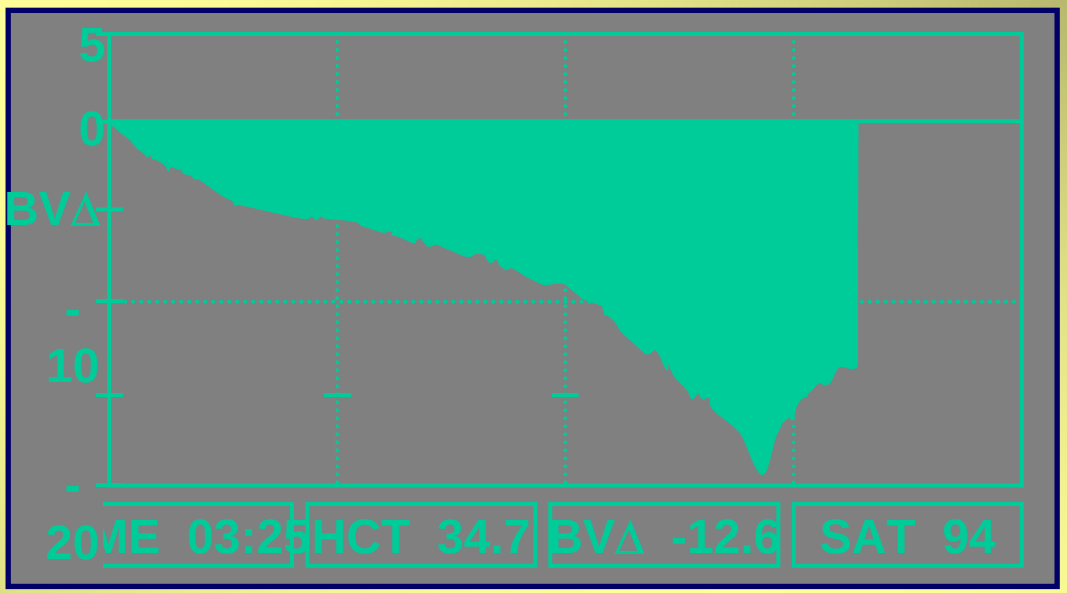
(1) Total body fluid overload and high interstitial pressure (PRR)

(2) Dry weight is too high

Caveat: Low UFR (small fluid gain or long dialysis)

Useful if high UFR and still has stable PV

Rapid decrease in Plasma Volume



Plasma Refilling Rate < Ultrafiltration Rate

Common Interpretation:

(1) Volume depleted and low interstitial pressure (PRR)

(2) Dry weight is too low

Caveat:

High UFR (intravascular volume depletion despite edema)

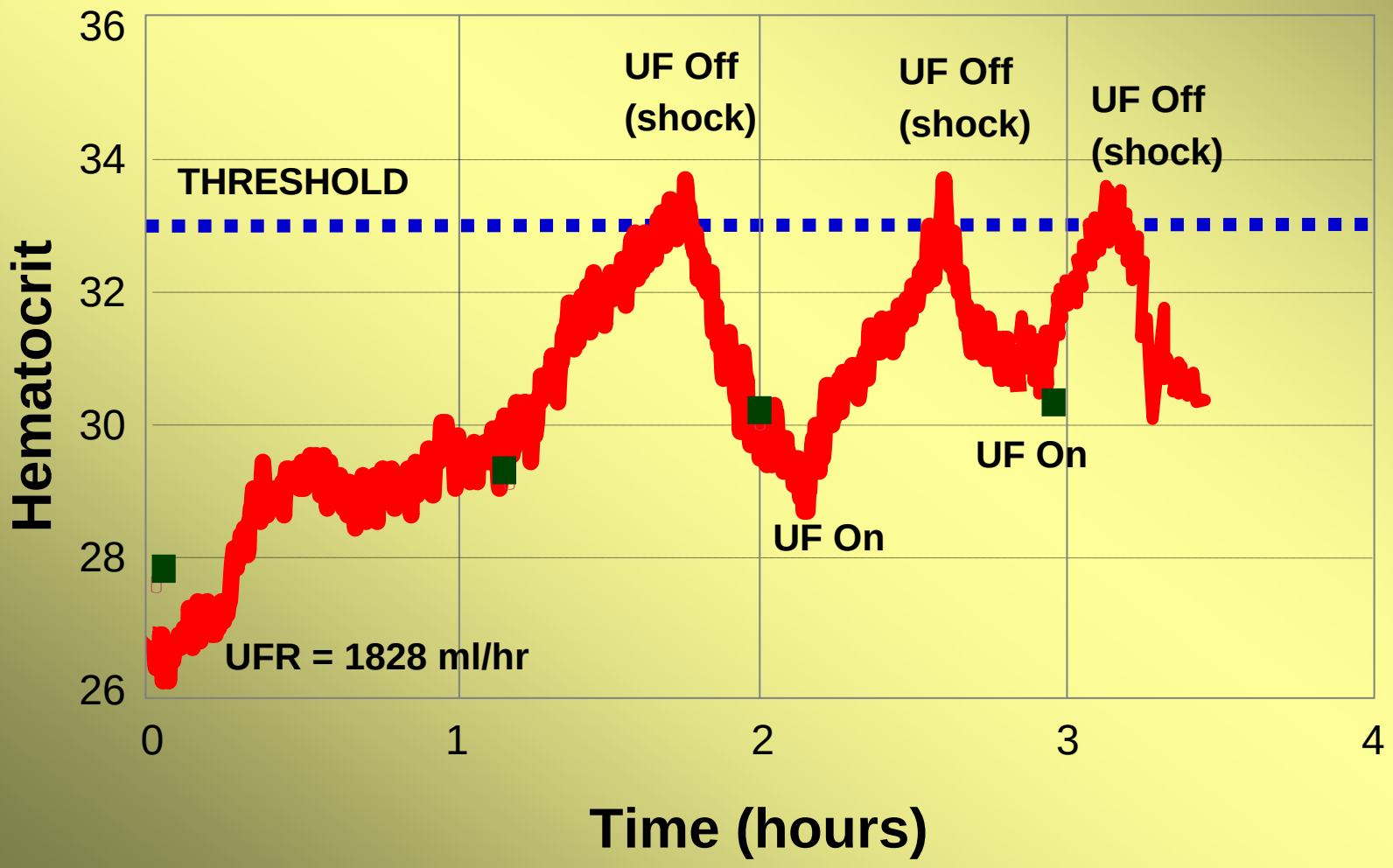
BLOOD VOLUME MONITOR

- How to use Volume Monitor

to predict and prevent

Intradialytic Hypovolemic Symptoms?

CONCEPT OF CRITICAL BLOOD VOLUME



HEMATOCRIT THRESHOLDS

PATIENT	# SESSIONS	THRESHOLD HEMATOCRIT	SESSIONS WITH SYMPTOMS
1	14	51.0+/-1.2	6
2	11	40.9+/-1.3	6
3	12	35.8+/-1.1	5
4	8	36.7+/-1.2	2
5	10	41.4+/-0.4	6

BLOOD VOLUME MONITOR: PREDICTIVE ABILITY

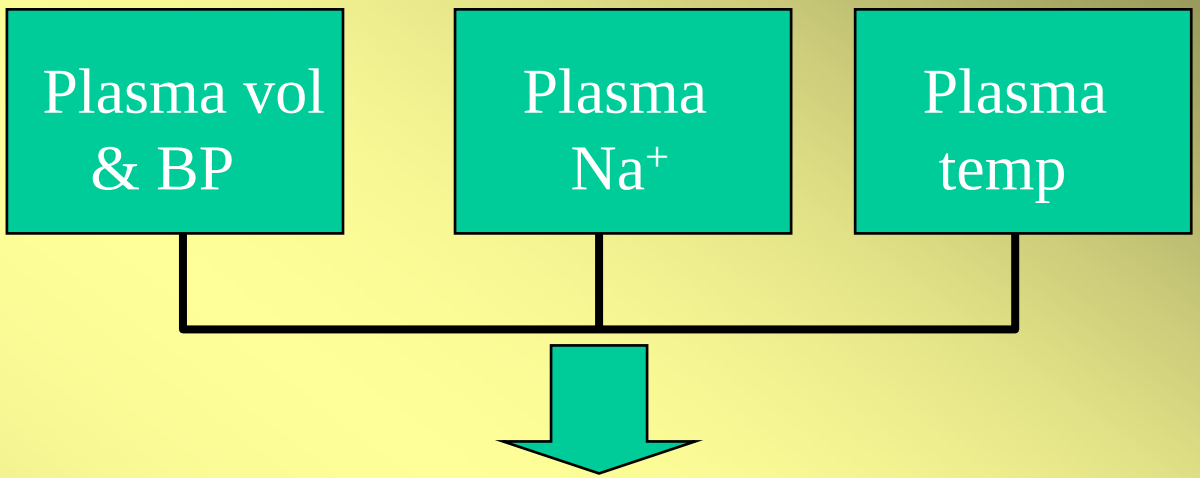
- n = 13 HYPOTENSION-PRONE HD PATIENTS
- RELATIVE BLOOD VOLUME MEASUREMENT
- 8/13 HAVE RBV DEFINED BELOW WHICH > 92% HYPOTESIVE EPISODES OCCUR

RBV PREDICTS EPISODES IN 62% OF HYPOTENSION-PRONE PATIENTS

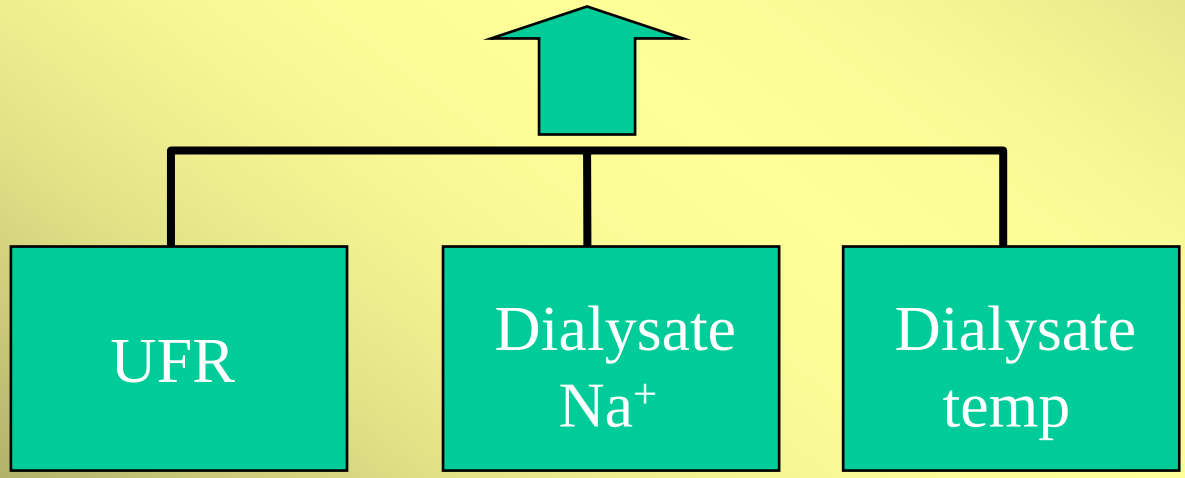
SIGNALS & RESPONSES FOR INTEGRATED BIOFEEDBACK SYSTEM

Signals from Patient

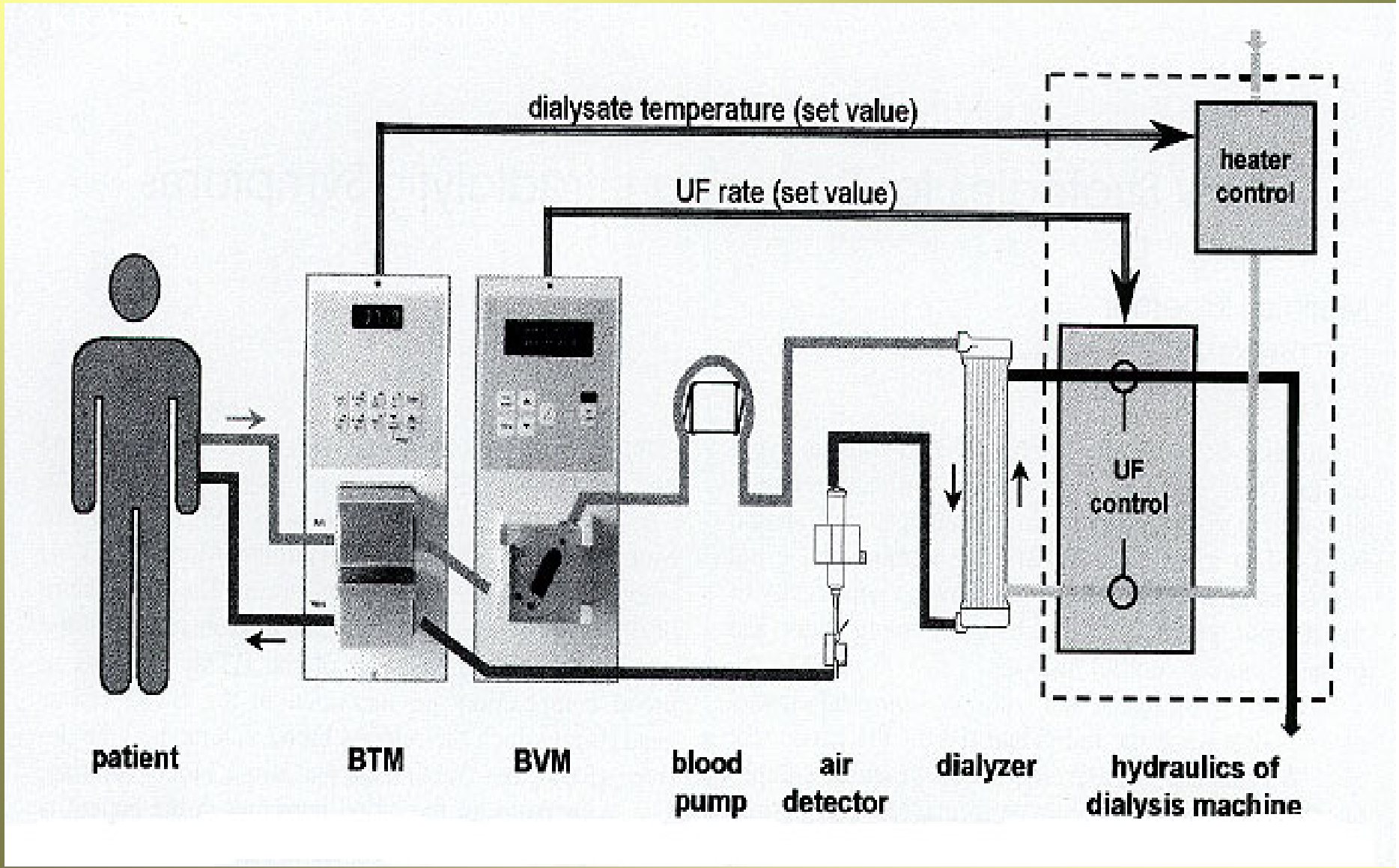
UF volume



Responses from machine



FRESENIUS BLOOD TEMPERATURE AND VOLUME MONITOR



EXPERIENCE WITH AN INTEGRATED BIOFEEDBACK SYSTEM AJKD 32:738, 1998

n = 8 PATIENTS, 96 treatments	STANDARD HD	BIOFEED-BACK HD	STANDARD HD
SEVERE HYPO-TENSION	26	3	16
% DECLINE SBP	20+/-8.1	12.4+/-3.5	17.5+/-4.5
SALINE INFUSION Rx (cc)	160+/-50	60+/-35	95+/-30
ULTRAFILTRATE	3.1+/-0.6	3.5+/-0.5	3.2+/-0.7

INTERVENTIONS

- EVALUATE DRY WEIGHT
- TREAT REVERSIBLE CAUSES
- BELLS, WHISTLES AND GIZMOS
- ***MEDICATIONS***

MEDICATIONS TO SUPPORT BLOOD PRESSURE

- SALINE: LIMITED EFFICACY, EDW NOT ACHEIVED
- MANNITOL, DEXTRAN: RETENTION
- ALUBMIN: $$!
- ? HYDROXYETHYLSTARCH (10%): PRELIMINARY STUDIES SUGGEST SIMILAR EFFICACY TO ALBUMIN; NO LONG TERM STUDIES
- ? LIMIT EATING DURING DIALYSIS: MALNUTRITION ?
- MIDODRINE: MODEST EFFECT
- FLUDROCORTISONE: AUTONOMIC DYSFUNCTION; 1 MG (10X USUAL DOSE)

DIALYSIS TIME

- DIALYSIS TIME IS ULTIMATELY GOVERNED BY ULTRAFILTRATION REQUIREMENTS
- MULTIPLE LINES OF EVIDENCE SUGGEST COMPLICATIONS OF DIALYSIS ARE REDUCED BY LENGTHENING T_D
  - MORTALITY
  - HYPERTENSION
  - PHOSPHORUS CONTROL
- IT'S TIME TO CONSIDER A **"DIALYSIS TIME HYPOTHESIS"**

FUTURE DIRECTIONS

- **More definitive outcome measures**
  - What constitutes optimum dialysate?
  - What constitutes optimum dialysis time?
  - What are optimum dry weight & blood pressures?
  - What portion of the patients can benefit from given interventions?
  - How can these patients are identified?
- **Development of advanced biofeedback systems**
- **Introduction of alternative modalities of hemodialysis**

THANKS FOR YOUR ATTENTION!!