Strategies for Managing Hyperglycemia in the Critically Ill Patient on Nutrition Support

Tuesday, February 3, 2009
11-12:30

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Balancing nutrition and elevated blood glucose

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Disclosures

- I have no commercial relationships to disclose

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Objectives

- Describe the pathophysiology of stress-related hyperglycemia
- Recognize the risk of hyperglycemia associated with the delivery of parenteral nutrition (PN)
- Identify appropriate enteral nutrition (EN) formulas that can be utilized to minimize glycemic response in the ICU

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Hyperglycemia in Critical Illness

- DM vs. Stress-related hyperglycemia
  - Type I DM: insulin deficiency
  - Type II DM: peripheral insulin resistance
  - Stress: conterregulatory hormones and cytokines
    - Increased glycogenolysis
    - Increased gluconeogenesis
    - Increased insulin resistance

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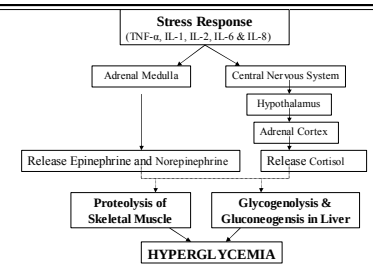
Hyperglycemia in Critical Illness



Adapted from Collier B, et al. *Nutr Clin Pract*. 2008;23:3

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Adding Fuel to the Fire

- Medications
  - Corticosteroids
  - Sympathomimetic infusions
  - Immunosuppressants
- IV Fluids
  - Resuscitation, fluid maintenance, or medication delivery
- Peritoneal Dialysis
- Nutrition Support in the ICU

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Parenteral Nutrition

- Hyperglycemia correlated with adverse outcomes
- Lin LY, et al. *Am J Med Sci.* 2007;333:261
  - Hyperglycemia increased mortality
  - Each 10 mg/dL increase in mean blood glucose was associated with increase infection, cardiac complications, renal and respiratory failure

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Parenteral Nutrition

- Glucose Oxidation Rate
  - the maximum glucose infusion rate is 4 mg/kg/minute
  - Rosmarin DK, et al. *Nutr Clin Pract.* 1996,11:151
- Conservative Initiation
  - Determine history of diabetes
  - Review medications
  - Initiate solution with ½ goal dextrose and monitor blood glucose response
  - McMahon MM. *Nutr Clin Pract.* 2004;19:120

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Parenteral Nutrition

- Lipid Calories
  - Caution when substituting lipid for dextrose calories
  - Wanten GJA, et al. AJCN. 2007;85:1171
- Minimize Duration
  - Initiate enteral nutrition when feasible
    - Surgical versus Medical ICU
  - For slow EN advancement:
    - Decrease PN dextrose and lipid calories as EN increases

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Enteral Nutrition

- Diabetic Formulas
  - Designed to promote glycemic control
  - Higher percentage of fat to carbohydrate than typical formulas
  - Varying compositions
    - Higher percentage of fat than
    - Fructose
    - MUFAs
    - Fiber

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Enteral Nutrition:

- Diabetic formulas in the ICU
  - Calorie distribution (%Prot/%CHO/%Fat)
    - Study formula: 20%/40%/40%
    - Control formula: 22%/49%/29%
  - Resulted in
    - Better blood glucose levels: 176.8±44 vs. 222.8±47
    - Better capillary gluvose levels: 163.1±45 vs. 216.1±55
    - Less insulin requirement: 8.73 (2.3-27.5) vs 30.2 (21.5-57.1)
  - No difference in vent days, length of stay, infection or mortality

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Diabetic Formulas

Formula	Kcal	% Prot	%CHO	%Fat	Fiber g/L	ω6:ω3
Diabetisource AC	1.2	20%	36%	44%	15	1.96:1
Nutren Glytrol	1	18%	40%	42%	15.2	3.5:1
Glucerna	1	16.7%	34.3%	49%	14.4	10.8:1
Glucern 1.2 Cal	1.2	20%	35%	45%	10	n/a
Glucerna Select	1	20%	31%	49%	21.1	5.7:1

Enteral Nutrition

- Considerations for diabetic formulas in the ICU
  - Protein content
    - Many critical ill formulations provide 25% protein
  - Fiber content
    - Fiber containing formulas should not be used during hemodynamic instability or low flow states
  - Omega-6:Omega-3 ratio
    - Higher concentrations of Omega-3 fatty acids are beneficial in ALI/ARDS and possibly sepsis

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Consider Under and Over Feeding

- PN: conservative calorie goals
  - Providing >25-30 kcals/kg may exacerbate hyperglycemia
  - Boitano M. Nutr Clin Pract. 2006;21:617
- EN: monitor volumes of feeding infused
  - only 60-75% of calories are delivered
  - Intentional hypocaloric prescriptions should be avoided

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Hyperglycemia in the ICU

Exogenous Sources

- **Glucose Administration**
  - Nutrition Support
  - IV fluids
  - IV drug administration
  - Peritoneal dialysis
  - Medications
    - Corticosteroids
    - Sympathomimetic infusions
    - Immunosuppressants

Endogenous Sources

- **Glucose Production**
  - Proteolysis
  - Glycogenolysis
  - Gluconeogenesis

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Insulin Administration and Evidence-Based Review of Current Literature for Glucose Control in the ICU

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Disclosures

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Objectives

- Distinguish the different formulations of insulin available and how to select therapy
- Evaluate the strengths and limitations of utilizing subcutaneous insulin versus an infusion of regular insulin in the ICU
- Summarize current clinical trials surrounding the management of glucose control in the ICU

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Pharmacology

Pharmacokinetics

Dose

Absorption
Distribution
Metabolism
Elimination

Concentration in Plasma

Concentration at Site of Action

Pharmacodynamics

EFFECT

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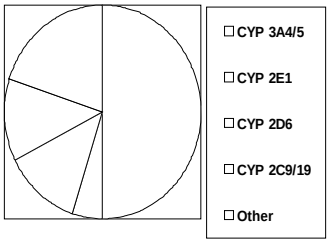
Chernow B. Pharmacology in Critically Ill Patient. 1994

Pharmacokinetic Drug Interactions

Interactions Affecting Metabolism

- Majority of interactions involve either inhibition or induction
- Combination of inhibition and induction reactions
- Monitoring of drug concentration levels may be necessary
- Liver is main source of CYP isoenzymes, but NOT the only source



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Goodman & Gilman. Pharmacology.2001

Variables in the ICU

- Pharmacokinetics- PK
  - A: Fluid balance and vasoactive agents
  - D: Volume of distribution
  - M: Renal and Hepatic function
  - E: Renal and Hepatic function
- Pharmacodynamics- PD
  - Concentration to drug effect
  - Concomitant medications
  - Clinical efficacy and safety

Clinically the PD measure is more indicative of insulin effects on blood glucose then PK measure; however, both may play a role in the ICU

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Goodman & Gilman. Pharmacology.2001

Clinical Pearls

- Pancreas secretes insulin into the portal vein, thereafter the liver removes 50-60% before it reaches circulation
- Insulin secretion involves cAMP
- α-adrenergic agents action is inhibitory and dominates over the β-adrenergic stimulatory action

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Chernow B. Pharmacology in Critically Ill Patient. 1994

Clinical Pearls

- Insulin circulates in plasma as free-unbound hormone
- Insulin distributes in extracellular fluid
- Plasma insulin half-life is 5 to 9 min
- Major sites of insulin degradation are liver (40-60%), kidney (15-20%), and muscle

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Chernow B. Pharmacology in Critically Ill Patient. 1994

Insulin: Action/Effect

Table 1. Duration of Action of Standard Insulins and Insulin Analogues.*

Insulin	Onset of Action	Peak Action	Effective Duration
Standard			
Regular	30–60 min	2–3 hr	8–10 hr
NPH	2–4 hr	4–10 hr	12–18 hr
Zinc insulin (Lente)	2–4 hr	4–12 hr	12–20 hr
Extended zinc insulin (Ultralente)	6–10 hr	10–16 hr	18–24 hr
Analogues			
Lispro	5–15 min	30–90 min	4–6 hr
Aspart	5–15 min	30–90 min	4–6 hr
Glargine	2–4 hr	None	20–24 hr

* Serum insulin profiles are based on a subcutaneous injection of 0.1 to 0.2 unit per kilogram of body weight; large variation within and between persons may be noted. Data are from DeWitt and Hirsch.*

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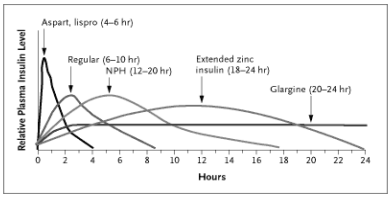
Hirsch I. *N Engl J Med.* 2005

Insulin: Action/Effect



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Hirsch I. *N Engl J Med.* 2005

Current Literature: as of December 2008

- Tight glycemic control: BS 80-110 mg/dl
- Usual Care: BS 180-200 mg/dl
- Different patient populations: Medical, Surgical, and Neuro ICU's
- Balancing risk and benefit from an intervention
- Severity of illness (ie APACHE II score) of patients

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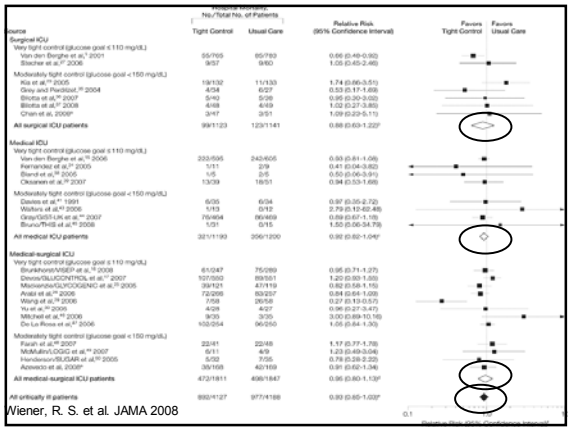
Table 2. Glucose Goals and Mean Achieved Levels in Trials Included in the Final Meta-Analysis

Source	Tight Control: Glucose Goal, mg/dL	Tight Control: Glucose Achieved, Mean (SD), mg/dL	Usual Care: Glucose Goal, mg/dL	Usual Care: Glucose Achieved, Mean (SD), mg/dL
Surgical ICU				
Very tight control, glucose goal ≤110 mg/dL				
van den Berghe,[7] 2001	80-110	104 (2[illegible])	180-200	153 (33)
van Wezel,[15] 2006	72-99	95 (NA)[a]	<200	124 (NA)
Stecher,[27] 2006[b]	80-110	NA	140-180	NA
Moderately tight control, glucose goal <150 mg/dL				
Gray,[8] 2004	80-120	125 (36)	180-220	179 (61)
Biotta,[16] 2007	80-120	93 (16)	<220	147 (25)
Biotta,[17] 2008	80-120	92 (18)	<220	147 (25)
Kia,[11] 2009[b]	75-115	109 (33)	180-200	144 (42)
Chan[c]	80-120	127 (NA)	<200	168 (NA)
Medical ICU				
Very tight control, glucose goal ≤110 mg/dL				
Bland,[18] 2005	80-110	105 (26)	180-200	177 (46)
van den Berghe,[19] 2006	80-110	111 (29)	180-200	153 (31)
Oksanen,[20] 2007	72-108	90 (23)[a]	108-144	115 (23)[a]
Fernandez,[21] 2008[b]	80-110	120	<150	205
Moderately tight control, glucose goal <150 mg/dL				
Davies,[22] 1991	72-144	185 (38)	<180	193 (65)
Walters,[23] 2008	90-144	124 (18)	<270	146 (14)
Gray,[24] 2007 (GIST-UK)	72-126	113 (NA)	<306	122 (NA)
Bruno,[25] 2008 (THS)	90-130	133 (16)	<200	190 (64)
Medical-surgical ICU				
Very tight control, glucose goal ≤110 mg/dL				
Yu,[26] 2005	80-110	103 (23)	180-200	198 (29)
Mitchell,[28] 2006	80-110	97 (NA)[a]	180-200	142 (NA)[a]
Wang,[29] 2006	80-110	99 (68)	180-200	185 (25)
Brunkhorst,[30] 2008 (VISEP)	80-110	112 (NA)	180-200	151 (NA)
Iapichino,[31] 2008	80-110	110 (17)	180-200	153 (29)
Mackenzie,[32] 2005 (GLYCOGENIC)[b]	72-108	126 (43)	180-198	151 (43)
Arabi,[33] 2009[b]	80-110	115 (18)	180-200	171 (34)
De La Rosa,[34] 2006[b]	80-110	NA	180-200	NA
Devos,[35] 2008 (GLUCONTROL)[b]	80-110	119 (NA)	140-180	147 (NA)
Moderately tight control, glucose goal <150 mg/dL				
Farah,[36] 2007	110-140	142 (14)	140-200	174 (20)
McMullin,[37] 2007 (LOGIC)	90-126	128 (47)	144-180	169 (38)
Henderson,[38] 2005 (SUGAR)[b]	72-126	NA	162-200	NA
Azevedo[d]	80-120	134 (NA)	<180	144 (NA)

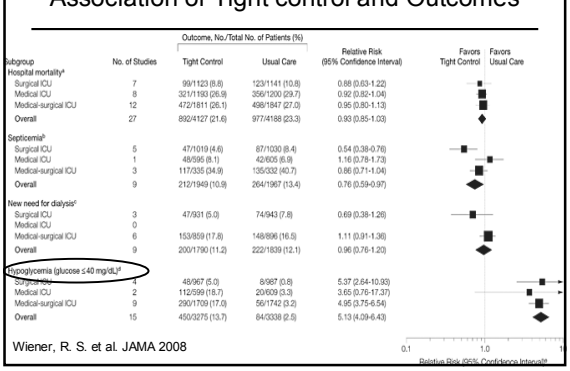
Abbreviations: ICU, intensive care unit; NA, not available from manuscript or authors.
[a] Conversion factor: To convert glucose to mmol/L, multiply values by 0.0555.
[b] Achieved score is approximate.
[c] Denotes abstract that was presented at a meeting but not yet published.
[d] Denotes unpublished data.

Wiener, R. S. et al. JAMA 2008



Wiener, R. S. et al. JAMA 2008

Association of Tight control and Outcomes



Wiener, R. S. et al. JAMA 2008

Current Literature: as of December 2008

- A momentum change from tight glucose control (80-120 mg/dl) to (less than 150 mg/dl) for all ICU populations
- Different patient populations and time periods of evaluation
- Nutritional approach to patients with hyperglycemia
- Consideration of external variables which can affect patient care and outcomes
- Careful approach to the management of hypoglycemia

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Hypoglycemia

- Glucose as a major fuel source for the brain
- Glucose synthesis and storage within astrocytes is not metabolically possible
- Defined generally in clinical trials as blood glucose less than 40 mg/dl
- Generally an iatrogenic manifestation of therapy

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Cryer P. *J Clin Invest*. 2007

Hypoglycemia

- Average BS less than 20 for period of 5 to 6 hours was suggestive of neurological damage
- NADPH oxidase activation occurs during glucose re-perfusion
- Superoxide formation also contributes
- Elevation of glucose into physiological range of 70 mg/dl seems more appropriate

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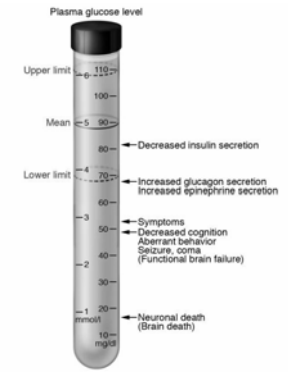
Cryer P. *J Clin Invest*. 2007



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Cryer P. *J Clin Invest*. 2007

Identification of Genetic Polymorphism for Hyperglycemia

- Title: Toll-like receptor 4 polymorphism predicts early hyperglycemia
- Background: Hyperglycemia has been linked to the T399I polymorphism
  - Hypothesis- TLR4 regulates the interface between the genome and metabolic response to injury
- Methods: 1118 Trauma patients were obtained from a de-identified repository
  - TLR4 gene on Chromosome 9 distinguished between wild type (CC) and heterozygote (CT)

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Collier BR et al. ASPEN Poster Session. 2009

Identification of Genetic Polymorphism for Hyperglycemia

- Results:
  - 139 (12.4%) had CT, 979 (87.6%) had CC genotype, respectively
  - Univariate analysis demonstrated CT patients were more likely to develop acute hyperglycemia then CC patients (p=0.02)
  - No significant differences in outcome (VAP, ALI, transfusion, mortality) between the two groups
  - After adjusting for survival, CT remained predictor for acute hyperglycemia *(blood sugar greater than 250 mg/dl)* with OR 2.23 CI (1.42-3.52)

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Collier BR et al. ASPEN Poster Session. 2009

Identification of Genetic Polymorphism
for Hyperglycemia: *Discussion Points*

- *Blood sugar greater than 250 mg/dl on multiple readings*
  - How is the genetic information from the patient going to be used in clinical practice at the bedside?
  - If outcome is affected by hyperglycemia, why was this not observed by the investigators in the trial?
  - TLR4 activation has been well documented with gram-negative infections, will the same findings hold for gram-positive, fungal, etc?
  - Was administration of nutrition and catecholamine infusions balanced among the two groups?
  - Will the assay results be faster than standard laboratory methods with arterial blood sample?

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Next Steps

- Utilization of a practice standard in your ICU for hyperglycemia management
  - Insulin administration *(SC versus infusion)*
  - Method of glucose monitoring *(arterial versus plasma)*
  - Protocol implementation *(electronic versus paper)*
  - Weighing the risks and benefit of glucose control *(less than 150 mg/dl)*

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Tight Glycemic Control in the ICU: Practical Concerns

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I have no commercial relationships to disclose

Objective: Upon completion of this session, the learner will be able to discuss practical considerations in implementing tight glycemic control (TGC) in the ICU setting.

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ICU management of hyperglycemia

- Glucose-insulin-potassium infusions
- Addition of insulin to TPN
- Scheduled subcutaneous insulin
- Intravenous insulin infusion

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"…as a result of trial performed in critically ill patients, intensive monitoring and treatment of glucose levels in critically ill patients is emerging as a standard of care for these patients."

Critical Care Med 2007; 35:2262

"…critical evaluation of published work indicates that the evidence for the benefit of this therapy may not be as compelling as previously indicated, and its widespread use may have been premature."

Nursing in Critical Care 2007; 12:202-210.

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Tight glycemic control (TGC) in the ICU: clinicians' concerns

- confusion re: importance of tight control
- treatment targets
- measurement issues
- fear of hypoglycemia
- calculation mishaps
- patient comfort/blood loss
- resources/workload/costs

Intensive Care Medicine 2004; 30:798-803

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Protocol-driven care

- Enhance clinical decision-making
- Facilitate evidence-based practices
- Improve outcomes
- Enhance efficiency
- Decrease potentially-harmful practice variations

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TGC Protocol: Potential Problems

- one size doesn't fit all: diagnoses, organ dysfunction, diabetes, CHO exposure, severity of illness, concomitant therapies
- familiarity/complexity/potential for error
- time/staffing/workload adjustments
- attitudes/ adherence 50-75%
- protocol muddles: HHNK, DKA, TGC (versions 1-3) , investigational

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Key Points: Protocol Adherence

Barriers
- Resistance to change
- Lack of awareness/experience
- Resource constraints
- Slow administrative processes
- Workload
- Numerous guidelines
- Complexity
- Paucity of evidence
- outdates

Enablers
- Team consensus
- Opinion leader
- Easy accessibility
- Ease of application
- Incorporation into daily routine
- Allowance for off-protocol adjustments

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Sampling site for glucose determination in critical illness?

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Table 3 -- Percent agreement between tested method of glucose measurement and the laboratory reference standard method

		Values per Patent Group (95% Confidence Interval)			
		Vasopressor-Dependent	Edematous	Postsurgical	All
Analysis and Value, mmol/L		% Agreement	% Agreement	% Agreement	% Agreement
Glucose meter, capillary blood (fingersticks)					
	<4.5	25.0	23.8	33.3	26.3
	≥4.5	71.4	86.4	60.0	71.3
	Total	61.1	55.8	53.8	56.8
Glucose meter, arterial blood					
	<4.5	50.0	55.0	62.5	55.6
	≥4.5	73.1	86.4	72.4	76.6
	Total	67.6	71.4	70.3	69.9

Table 4 -- Zone distribution of paired differences between tested method of glucose measurement and reference standard from modified error-grid analysis for all patients

		Distribution of Paired Differences From Modified Error-Grid Analysis			
Modified Error-Grid Analysis Zone	**Comparison with Reference Standard**	**Glucose Meter, Capillary Blood (%)**	**Glucose Meter, Arterial Blood (%)**	**Blood Gas/Chemistry, Arterial Blood (%)**	**Clinical Interpretation**
Target zone		86 (73)	99 (88)	114 (99)	Target (acceptable error)
Hypoglycemia zone	Overestimation	11 **(9)**	6 **(5)**	0 (0)	**Risk of failure to detect and treat hypoglycemia**
	Underestimation	3 (3)	2 (2)	0 (0)	Risk of unnecessary treatment of hypoglycemia
Normoglycemia zone	Overestimation	11 **(9)**	3 **(3)**	0 (0)	Risk of unnecessary treatment of hyperglycemia
	Underestimation	2 (2)	1 (1)	1 (1)	Risk of unnecessary treatment of hypoglycemia
Hyperglycemia zone	Overestimation	4 (3)	1 (1)	0 (0)	Risk of overtreatment of hyperglycemia
	Underestimation	1 (1)	1 (1)	0 (0)	Risk of failure to detect and treat hyperglycemia
Total		118	113	115	

Key Points: Reliability of ICU point of care measurements

- Studies of glucometer and laboratory agreement suggest:
  arterial>venous>capillary (fingerstick)
- Inaccuracies may be greater in patients who are:
  - *hypoglycemic*
  - *hypotensive*
- Glucometer analysis may miss significant hypoglycemia in critically ill

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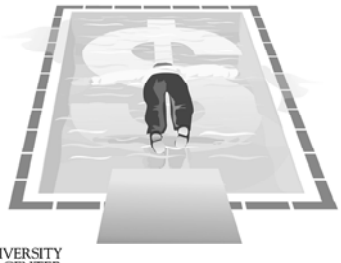
Costs of Tight Glycemic Control



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Krinsley JS, Jones, RL. Cost analysis of intensive glycemic control in critically ill adult patients. Chest 2006; 129:644-650

- comparison of costs of care pre and post TGC protocol (800 each group)
- single institution; 14 bed mixed med-surg ICU; community university-affiliated hospital; no cardiac surgery
- estimated cost savings per patient = $1,580

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Table 5. Resource Costs per Patient Based on Ventilation Status at the Onset of ICU Stay Chest 2006; 129:644*

Variables	Baseline	Treatment	p Value
Laboratory			
Total	1,091 (512–2,269)	795 (397–1,719)	< 0.001
No ventilation	725 (364–1,290)	573 (286–962)	0.004
Ventilation	2,032 (1,286–4,300)	1,693 (1,008–3,052)	0.012
Pharmacy			
Total	475 (165–1,361)	405 (164–1,037)	0.099
No ventilation	309 (131–781)	348 (125–711)	NS
Ventilation	1,020 (367–2,489)	808 (297–2,199)	NS
Imaging			
Total	1,062 (354–2316)	848 (308–1,822)	0.003
No ventilation	657 (208–1,769)	597 (226–1,533)	NS
Ventilation	1,707 (773–3,360)	1,348 (557–2,400)	0.004
Total			
Total	2,832 (1,296–5,757)	2,145 (1,142–4,577)	< 0.001
No ventilation	1,715 (939–3,369)	1,560 (938–2,809)	NS
Ventilation	5,483 (3,110–11,326)	4,661 (2,339–9,499)	0.029

"Savings were not shared equally among the different groups of patients.." Table 1. Diagnostic Categories of Patients*

Services	Baseline	Treatment
Medical	502	525
Cardiac**	169	175
Respiratory	115	125
GI**	63	64
Septic shock	43	45
Other	112	116
Surgical service**	298	275

Data are presented as No.
** Cost savings with treatment

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Time is money….
or
"costs" of protocol implementation

- protocol development
- staff education/training
- protocol implementation/maintenance
- equipment/quality control
- on-going monitoring/evaluation/outcomes
- explanations to patients, families
- remediation

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TGC
TIME:COST OBSERVATIONS

Author	Observations	Glucose Target	Time Required	Cost
Aragon	21	80-110	4.7 min; 2 hrs/pt/day	$250,000/yr **salary, time, training, supplies**
Malesker	454	70-120	• **Measurement: 5 min** • **Intervention: Hypo + 2 min Hyper + 11 min**	
Ruckelmann	? in 1 month	? "tight"	184hrs/pt/yr; 487 if isolated	1 FTE per 7 pts in isolation

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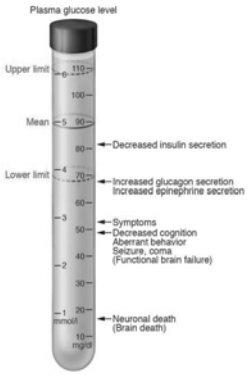
Severe Hypoglycemia: Another "cost" of TGC



J. of Clinical Investigation. 2007; 117:868

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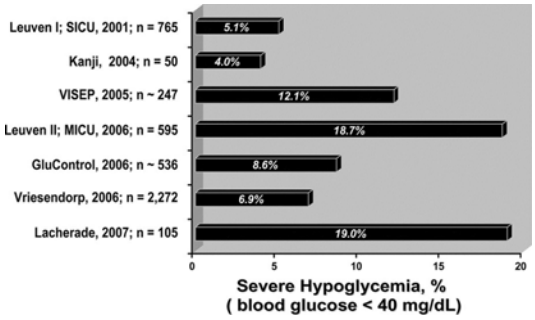
Incidence of Severe Hypoglycemia with TGC



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Nasraway, SA. Crit Care Med 2007; 35:10. 2437

Key Points: Costs of TGC

- total costs considerations: expenditures (e.g. resources consumed) and savings (decreased LOS)
- cost advantages/disadvantages will likely differ among patient groups
- optimal balance of TGC expenditures and savings is uncertain

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Severe hypoglycemia in critically ill patients: Risk factors and outcomes

- retrospective, data review; case:control methodology matching 102 SH pts with 3 controls
- Mortality in SH pts = 56% in controls= 40%
- Multivariable regression analyses to identify independent risk factors for hypoglycemia and death.

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Krinsley & Grover. Critical Care Med 2007; 35:2262

Risk of severe hypoglycemia and mortality in the ICU

Risk of Severe Hypoglycemia
- Diabetes
- Septic shock
- Mechanical ventilation
- TGC treatment
- APACHE II

Risk of Death
- Mechanical ventilation
- Severe hypoglycemia
- APACHE II
- Age
- TGC treatment

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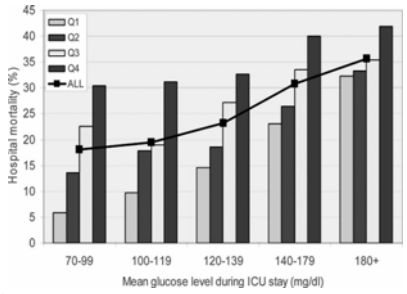
ICU Mortality and Glycemic Variability



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Key Points: Hypoglycemia

- Hypoglycemia causes) brain fuel deprivation and (usually reversible) brain failure
- Subtle signs of hypoglycemia are difficult to detect in critically illness
- Even a single episode of severe hypoglycemia is associated with a increased risk of mortality
- Glycemic variability may be an important factor in determining prognosis with TGC

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Key Points: S (safe) GC

- Adopt a safe glycemic target appropriate to the skills, experience, and available tools of the ICU
- Adjust to minimize hypoglycemic events, glucose variability
- Utilize sensible monitoring technologies

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Krinsley JA & Preiser J. Critical Care 2008; 12:149