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Neurodevelopmental Outcomes: How May We Improve?

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Disclosures

I have no real or perceived conflicts of interest related to this talk

I will not be discussing off-label use of drugs or devices

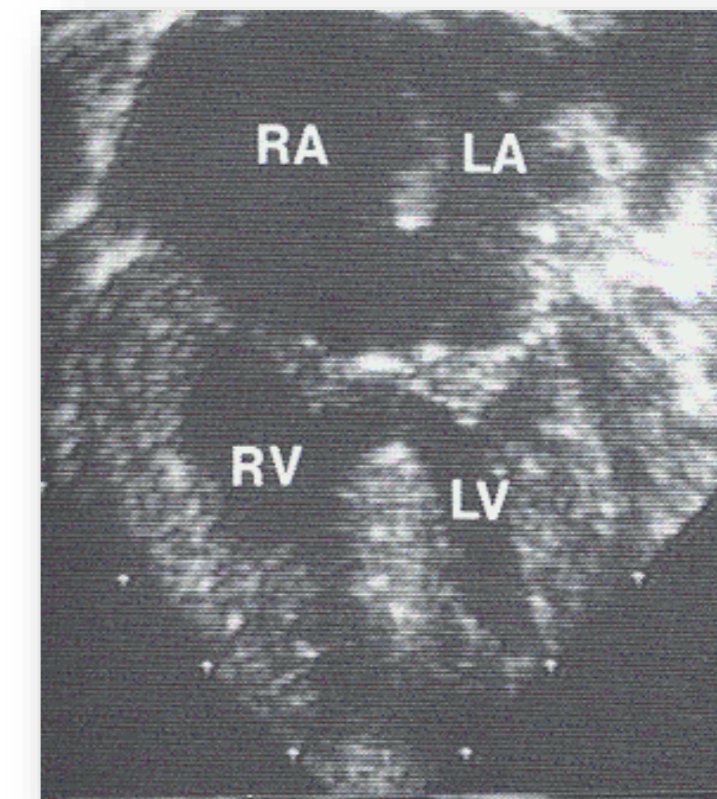
Outline - The Perioperative Period & The Operating Room

- Pre-operative risks
- Timing of Surgery
- Risks of Surgery/Circulatory Support/Anesthesia
- Risks During The ICU Course, Including Sedation
- New Strategies for Improvement

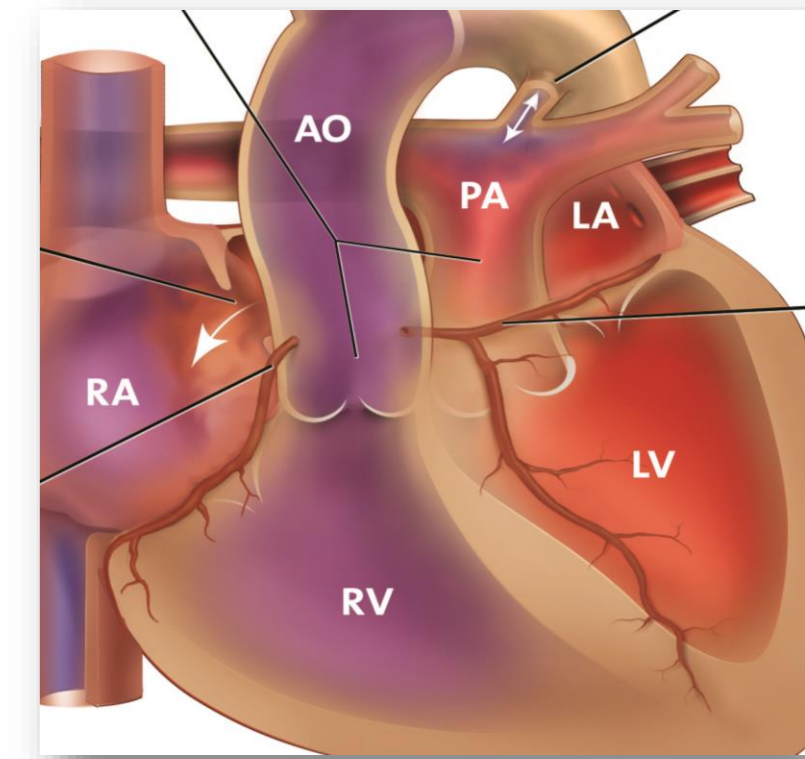
Physiologic Fact #1 - Mixing of Systemic and Pulmonary Venous Return

Before (and occasionally after) Cardiac Surgery

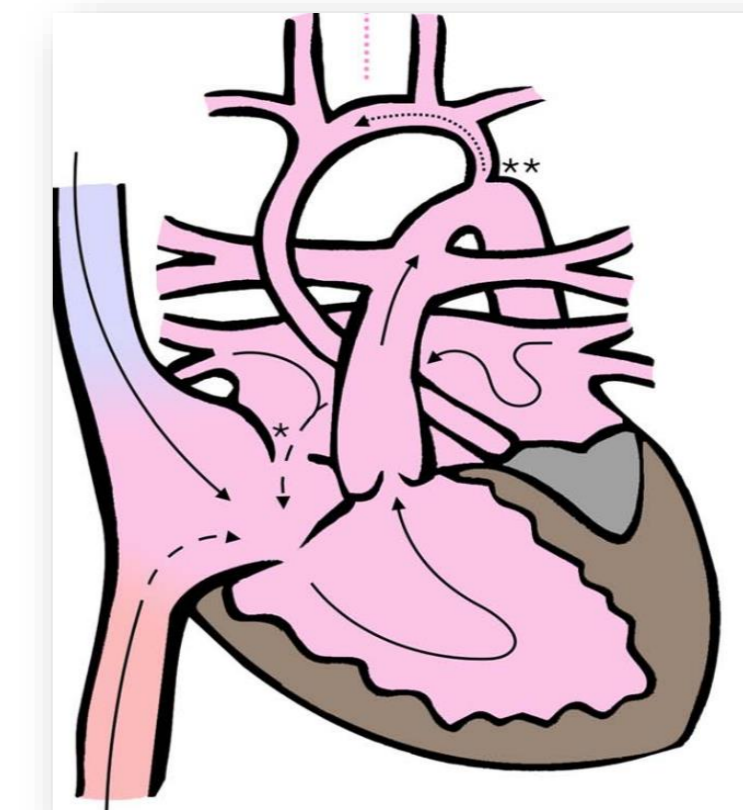
- Low Oxygen Delivery
 - Hypoxemia
 - ↓ Cardiac Output



AVSD



TGA



HLHS

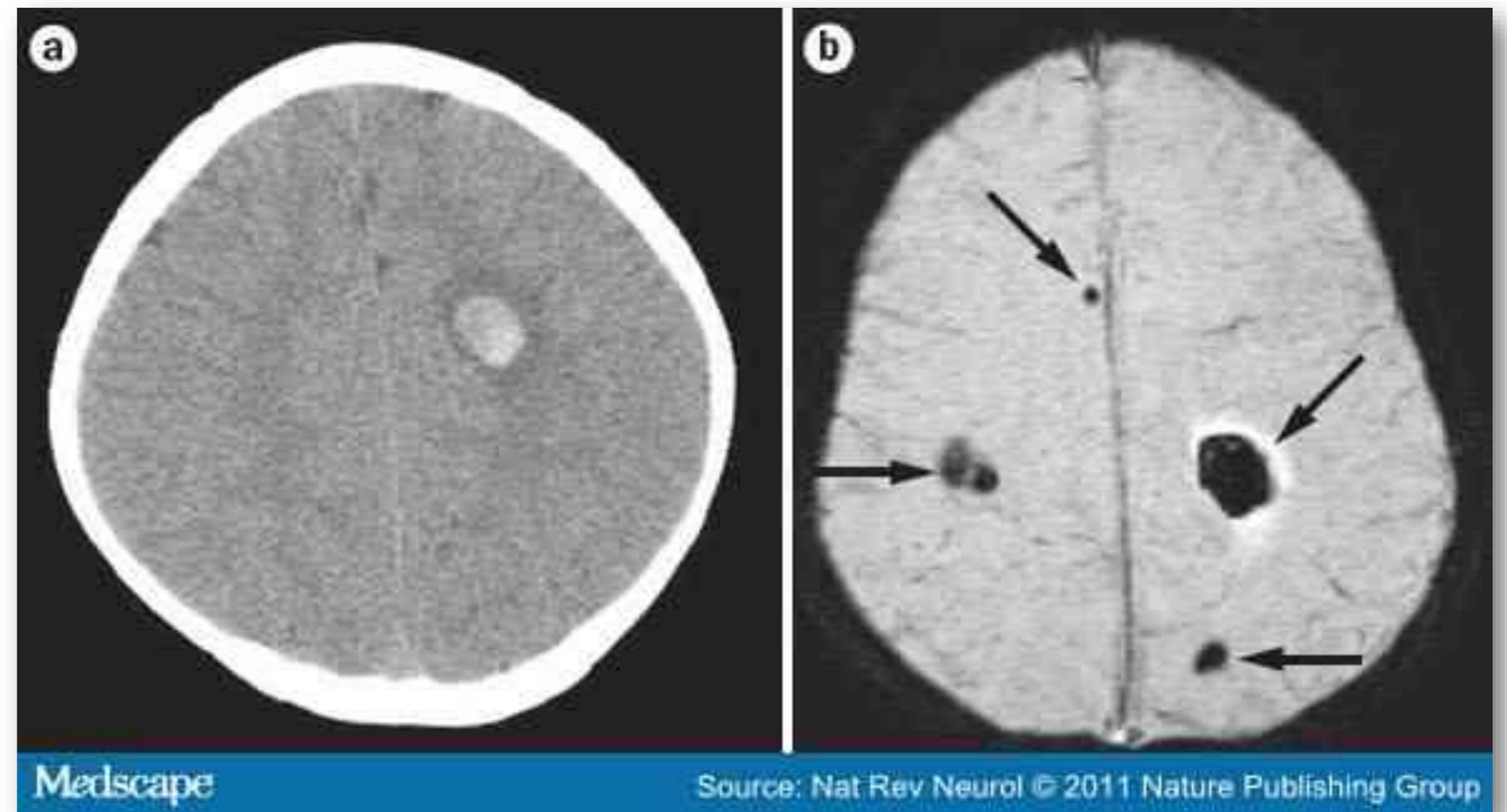


Physiologic Fact #1 - Mixing of Systemic and Venous Return

Before (and occasionally after) Cardiac Surgery

- Low Oxygen Delivery
 - Hypoxemia
 - ↓ Cardiac Output

Risk of Stroke from Paradoxical Embolus



Physiologic Fact #1 - Mixing of Systemic and Venous Return

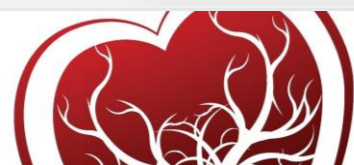
Before (and occasionally after) Cardiac Surgery

- Risk of Paradoxical Embolus



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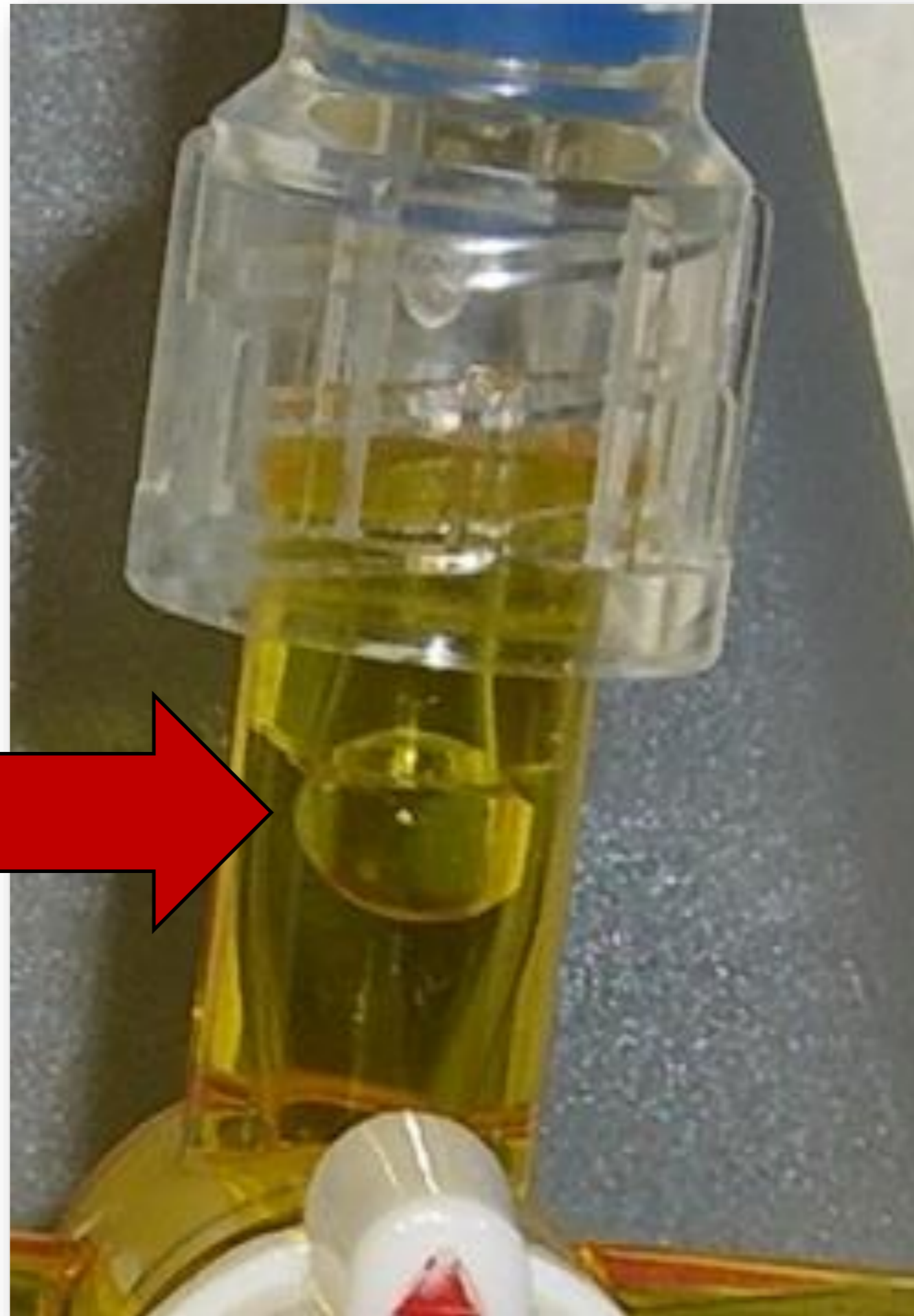
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Physiologic Fact #1 - Mixing of Systemic and Venous Return

Before (and occasionally after) Cardiac Surgery

- Risk of Paradoxical Embolus
 - Air
 - Particulate



Physiologic Myth #1 - "The Baby is Stable on Prostaglandin"



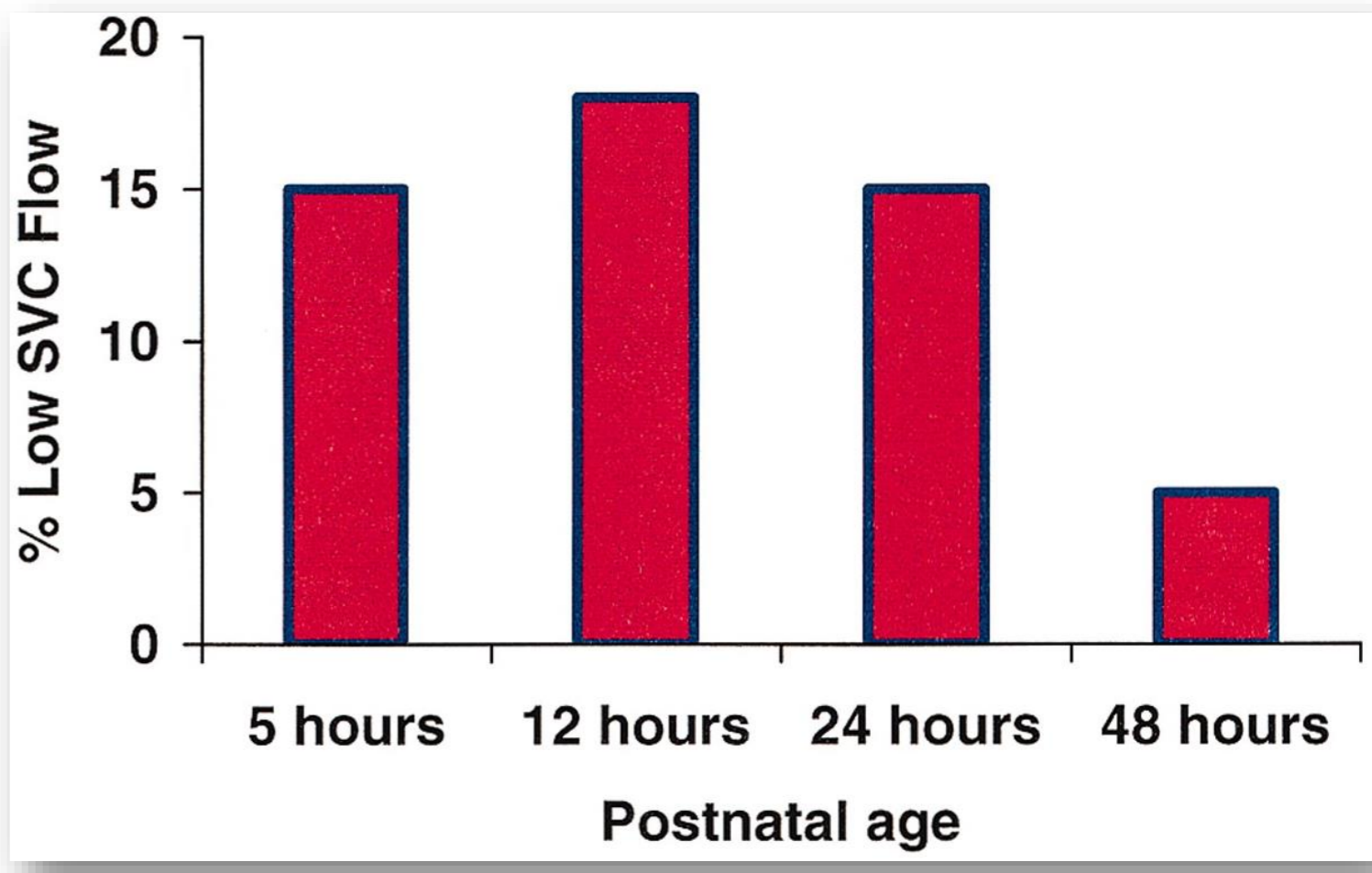
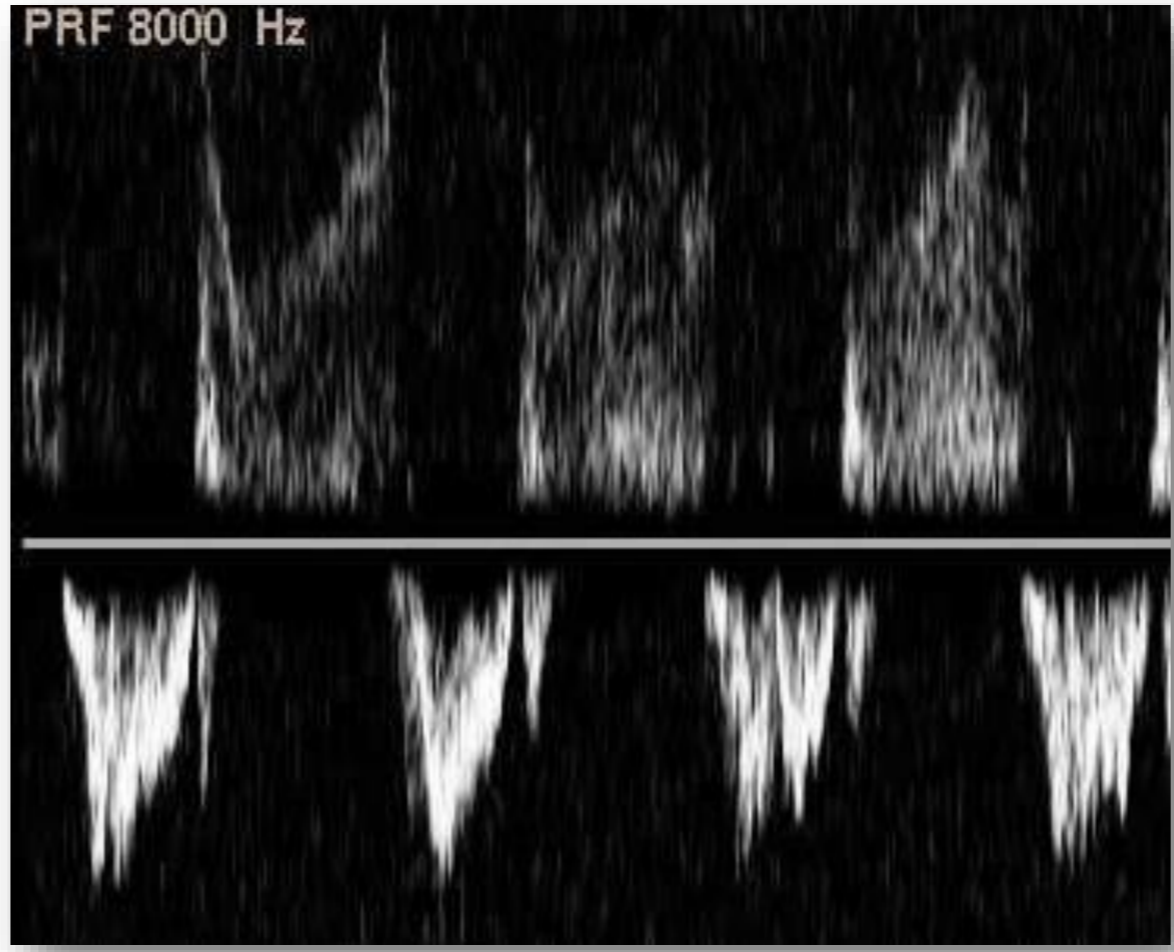
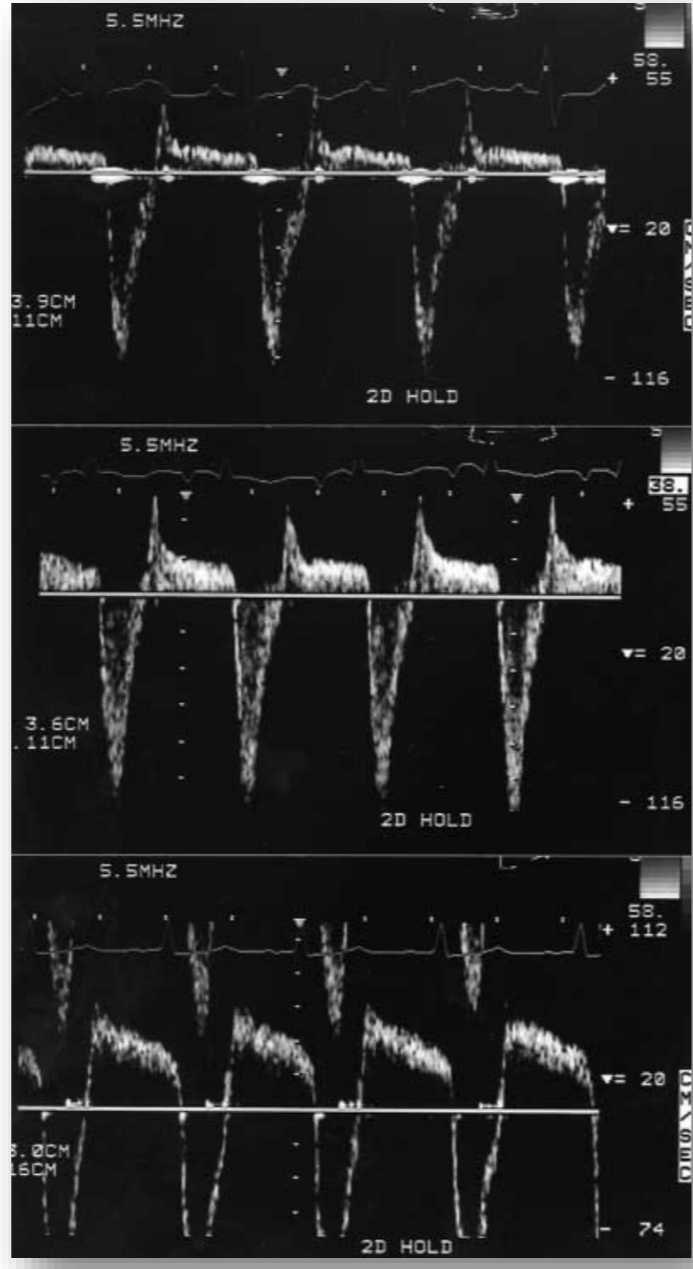
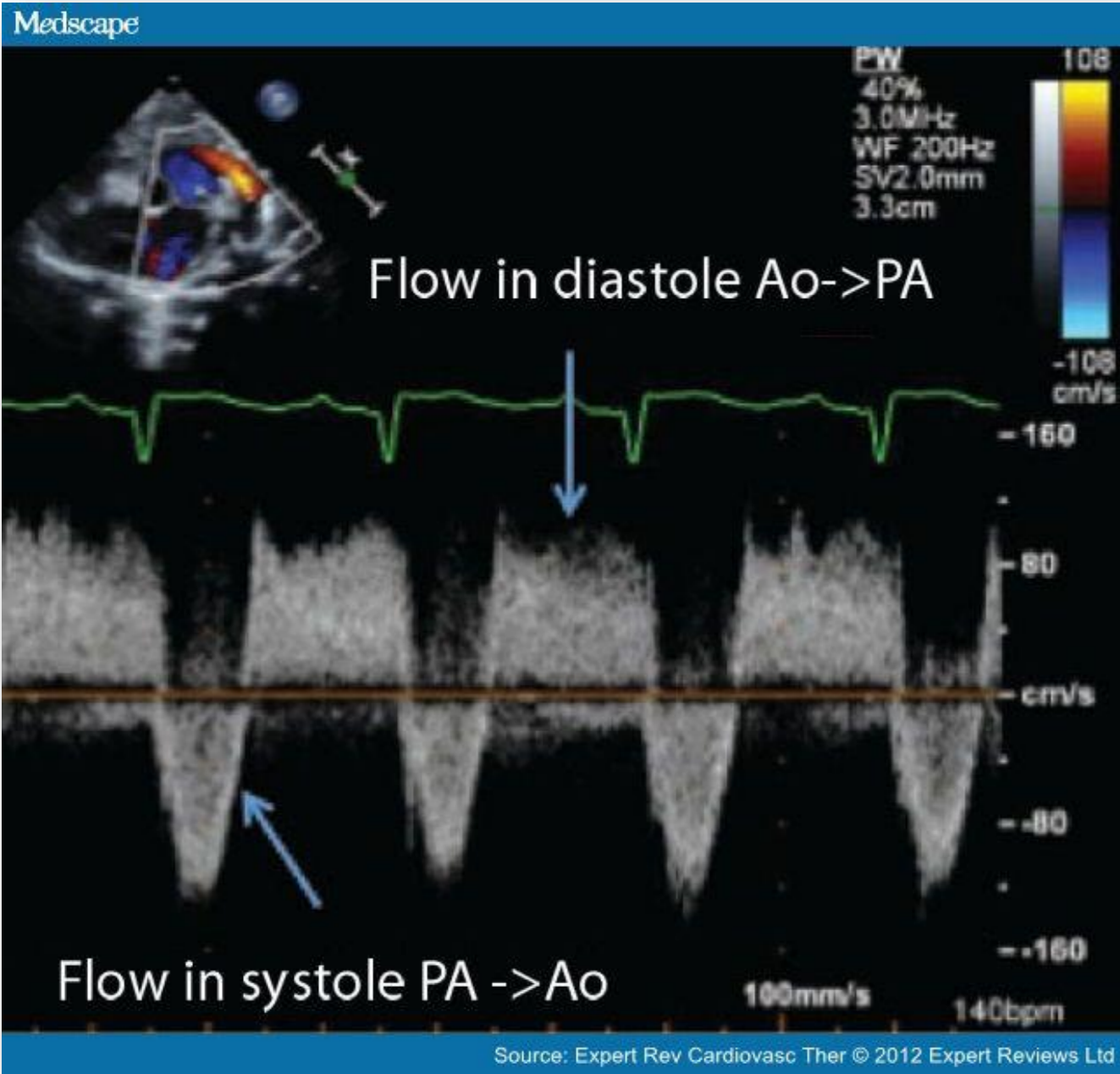
Physiologic Fact #2 - "A Baby is in Progressive CHF on Prostaglandin"

There is a "ductal steal" in diastole

↑ over time

↑↑↑ over time

↓↓ cerebral blood flow



Rychik J, Bush DM, Spray TL, Gaynor JW, Wernovsky G. J Thorac Cardiovasc Surg 2000;120:81-7.

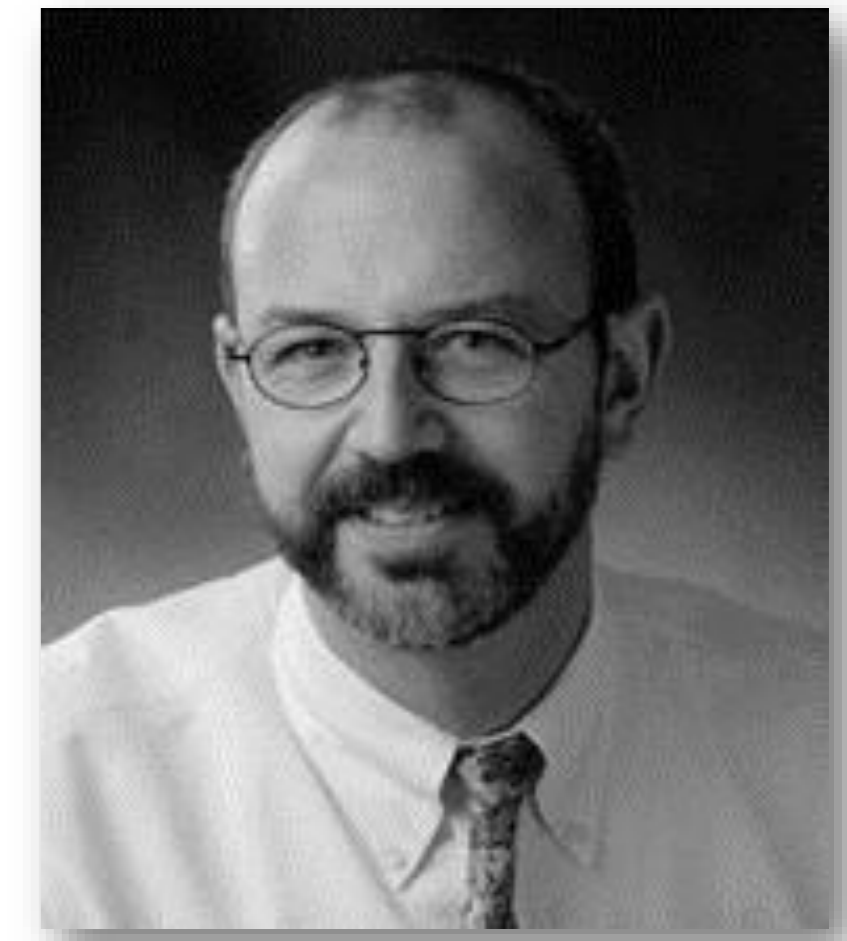
↑ Risk NEC
↑ Risk renal dysfunction

Kluckow M, Evans N, Osborn D. NeoReviews 2004;5:e98-e108

What Are The Effects of a *Delay in Surgery for cCHD* on the Brain?

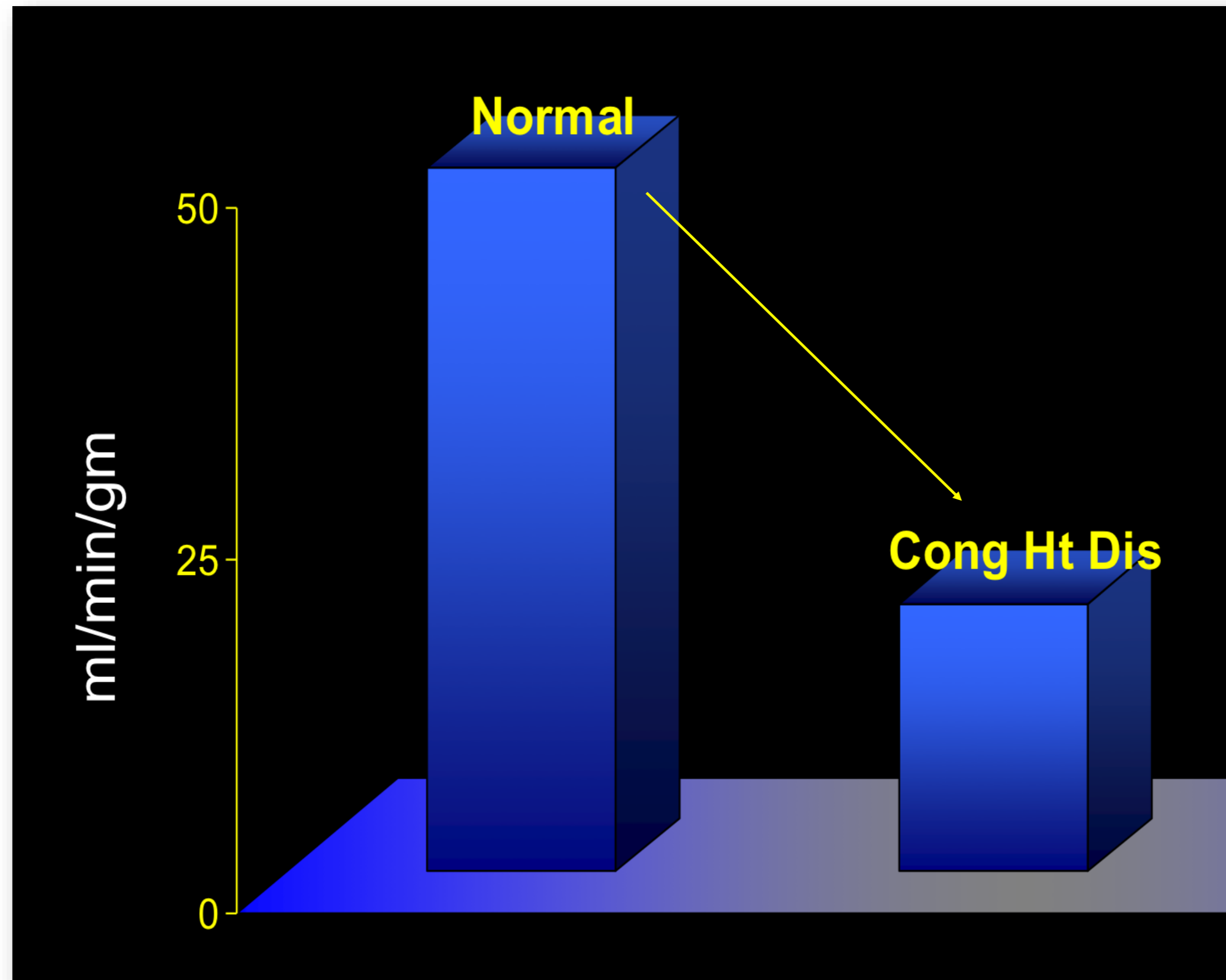
Cerebral Blood Flow is Diminished

48-72 hour Old Neonates on Prostaglandin



Daniel Licht, MD

~50 ml/min/gram
of brain



~25 ml/min/gram
of brain

Licht DJ et al
J Thorac Cardiovasc Surg 2004

Cerebral Oxygen Delivery Falls DAILY

Cerebral oxygen metabolism in neonates with congenital heart disease quantified by MRI and optics

Cerebral Blood Flow Falls Daily!

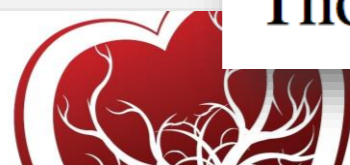
postoperative white matter injury in neonates with hypoplastic left heart syndrome

Jennifer M. Lynch, PhD,^a Erin M. Buckley, PhD,^{a,b,c} Peter J. Schwab, BS,^c Ann L. McCarthy, BBA,^c Madeline E. Winters, BA,^c David R. Busch, PhD,^c Rui Xiao, PhD,^d Donna A. Goff, MD, MS,^e Susan C. Nicolson, MD,^f Lisa M. Montenegro, MD,^f Stephanie Fuller, MD,^g J. William Gaynor, MD,^g Thomas L. Spray, MD,^g Arjun G. Yodh, PhD,^a Maryam Y. Naim, MD,^h and Daniel J. Licht, MD^c



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By *Electively* Delaying Cardiac Surgery

↑ Risk of:

- White Matter Injury
 - Possible long term effects
- Medical Error
- ? Mortality



By *Electively* Delaying Cardiac Surgery

↑ Risk of:

- White Matter Injury
- Medical Error
- ? Mortality

- **Increases In:**
- **Cost**
- **Length of Stay**

Earlier Arterial Switch Operation Improves Outcomes and Reduces Costs for Neonates With Transposition of the Great Arteries

Brett R. Anderson, MD, MBA,* Adam J. Ciarleglio, PhD,† Denise A. Hayes, MD,*
Jan M. Quaegebeur, MD, PhD,‡ Julie A. Vincent, MD,* Emile A. Bacha, MD‡
New York, New York



What Are The Effects of *Intraoperative Circulatory Support* on the Brain?

The Effects of Mechanical Circulatory Support During Cardiac Surgery on the Brain

Brain injury with systemic inflammation in newborns with congenital heart disease undergoing heart surgery

ROSSITZA P. PIRONKOVA^{1,8}, JOSEPH GIAMELLI^{1,9}, HOWARD SEIDEN^{1,10}, VINCENT A. PARNELL², DOROTA GRUBER^{1,3}, CRISTINA P. SISON^{4,5}, CZESLAWA KOWAL⁶ and KAIE OJAMAA^{1,5,7}

DEVELOPMENTAL AND NEUROLOGIC EFFECTS OF ALPHA-STAT VERSUS PH-STAT STRATEGIES FOR DEEP HYPOTHERMIC CARDIOPULMONARY BYPASS IN INFANTS

Long-term neurodevelopmental outcomes in school-aged children after neonatal arterial switch operation

COMPARISON OF NEUROLOGIC OUTCOME AFTER DEEP HYPOTHERMIC CIRCULATORY ARREST WITH ALPHA-STAT AND PH-STAT CARDIOPULMONARY BYPASS IN NEWBORN PIGS

PERIOPERATIVE EFFECTS OF ALPHA-STAT VERSUS pH-STAT STRATEGIES FOR DEEP HYPOTHERMIC CARDIOPULMONARY BYPASS IN INFANTS

Cerebral oxygen metabolism in neonates with congenital heart disease quantified by MRI and optics

Arterial switch with full-flow cardiopulmonary bypass and limited circulatory arrest: Neurodevelopmental outcome

Tom R. Karl, MD*

Complex Neonatal Single Ventricle Palliation Using Antegrade Cerebral Perfusion

Robert L. Hannan, MD, Marion A. Ybarra, BS, Jorge W. Ojito, CCP, Francisco A. Alonso, RNFA, Anthony F. Rossi, MD, and Redmond P. Burke, MD

Selective Cerebral Perfusion: Real-Time Evidence of Brain Oxygen and Energy Metabolism Preservation

Jorge D. Salazar, MD, Ryan D. Coleman, BA, Stephen Griffith, MD, Jeffrey D. McNeill, MD, Megan Steigelman, MD, Haven Young, CCP, Bart Hensler, CCP, Patricia Dixon, MS, John Calhoun, MD, Faridis Serrano, PhD, and Robert DiGeromino, MD

Division of Congenital Heart Surgery, Texas Children's Hospital, Baylor College of Medicine, Houston, Departments of Neurosurgery and Cardiothoracic Surgery, University of Texas Health Science Center, San Antonio, and Department of Pediatrics, Wilford Hall USAF Medical Center, Lackland AFB, Texas

The effect of duration of deep hypothermic circulatory arrest in infant heart surgery on late neurodevelopment: The Boston Circulatory Arrest Trial

Brain magnetic resonance imaging abnormalities after the Norwood procedure using regional cerebral perfusion

Catherine L. Dent, MD,* James P. Spaeth, MD,¹ Blaise V. Jones, MD,* Steven M. Schwartz, MD,* Tracy A. Glauser, MD,² Barbara Hallinan, MD, PhD,² Jeffrey M. Pearl, MD,² Philip R. Khoury, MS,^{2,4} and C. Dean Kurth, MD²

Neuroprotection in Pediatric Cardiac Surgery: What is On the Horizon?

Dean B. Andropoulos, M.D., M.H.C.M., Kenneth M. Brady, M.D., R. Blaine Easley, M.D., and Charles D. Fraser Jr., M.D. Divisions of Pediatric Cardiovascular Anesthesiology and Congenital Heart Surgery, Texas Children's Hospital, and the Departments of Anesthesiology, Pediatrics, and Surgery, Baylor College of Medicine, Houston, Texas

Developmental Progress After Cardiac Surgery in Infancy Using Hypothermia and Circulatory Arrest

PATRICIA M. CLARKSON, M.B., BARTON A. MACARTHUR, PH.D., BRIAN G. BARRATT-BOYES, M.B., CH.M., RALPH M. WHITLOCK, M.B., AND JOHN M. NEUTZE, M.D.

Developmental and Neurological Status of Children at 4 Years of Age After Heart Surgery With Hypothermic Circulatory Arrest or Low-Flow Cardiopulmonary Bypass

David C. Bellinger, PhD, MSc; David Wypij, PhD; Karl C. K. Kuban, MD, MSc; Leonard A. Rappaport, MD; Paul R. Hickey, MD; Gil Wernovsky, MD; Richard A. Jonas, MD; Jane W. Newburger, MD, MPH

Neurodevelopmental Outcomes Following Regional Cerebral Perfusion with Neuromonitoring for Neonatal Aortic Arch Reconstruction

Dean B. Andropoulos, M.D., R. Blaine Easley, M.D., Ken Brady, M.D., E. Dean McKenzie, M.D., Jeffrey S. Heinle, M.D., Heather A. Dickerson, M.D., Lara S. Shekerdemian, MB ChB, Marcie Meador, RN, MS, Carol Eisenman, RN, Jill V. Hunter, MB BS, Marie Turcich, MS, Robert G. Voigt, MD, and Charles D. Fraser Jr., M.D. Departments of Pediatrics, Anesthesiology, Surgery, and Radiology, Baylor College of Medicine, and Divisions of Pediatric Cardiovascular Anesthesiology, Congenital Heart Surgery, Pediatric Cardiology, Pediatric Intensive Care, Pediatric Neuroradiology, and Developmental Pediatrics, Texas Children's Hospital, Houston Texas

Aortic arch reconstruction using regional perfusion without circulatory arrest*

Cheong Lim, Woong-Han Kim*, Soo-Cheol Kim, Jae-Wook Rhyu, Man-Jong Back, Sam-Se Oh, Chan-Young Na, Chong Whan Kim

Department of Cardiovascular Surgery, Sejong General Hospital, Sejong Heart Institute, Bucheon, Kyungki-do, South Korea

Relationship of Intraoperative Cerebral Oxygen Saturation to Neurodevelopmental Outcome and Brain MRI at One Year of Age in Infants Undergoing Biventricular Repair

Barry D. Kussman, MBBCh, David Wypij, PhD, Peter C. Laussen, MBBS, Janet S. Soul, MD, David C. Bellinger, PhD, James A. DiNardo, MD, Richard Robertson, MD, Frank A. Pigula, MD, Richard A. Jonas, MD, and Jane W. Newburger, MD, MPH

DEVELOPMENTAL AND NEUROLOGIC STATUS OF CHILDREN AFTER HEART SURGERY WITH HYPOTHERMIC CIRCULATORY ARREST OR LOW-FLOW CARDIOPULMONARY BYPASS

DAVID C. BELLINGER, PH.D., RICHARD A. JONAS, M.D., LEONARD A. RAPPAPORT, M.D., DAVID WYPJ, PH.D., GIL WERNOVSKY, M.D., KARL C.K. KUBAN, M.D., PATRICK D. BARNES, M.D., GREGORY L. HOLMES, M.D., PAUL R. HICKEY, M.D., ROY D. STRAND, M.D., AMY Z. WALSH, R.N., B.S.N., SANDRA L. HELMERS, M.D., JULES E. CONSTANTINOU, F.R.A.C.P., ENRIQUE J. CARRAZANA, M.D., JOHN E. MAYER, M.D., FRANK L. HANLEY, M.D., ALDO R. CASTANEDA, M.D., JAMES H. WARE, PH.D., AND JANE W. NEWBURGER, M.D., M.P.H.

Modified ultrafiltration may not improve neurologic outcome following deep hypothermic circulatory arrest*

Richard J. Myung^a, Paul M. Kirshbom^a, Matus Petko^a, Jeffrey A. Golden^b, Alexander R. Judkins^b, Richard F. Ittenbach^c, Thomas L. Spray^a, J. William Gaynor^a

SURGERY BY DIRECT VISION IN THE OPEN HEART DURING HYPOTHERMIA

Henry Swan, M.D., Irvin Zeavin, M.D. S. Gilbert Blount Jr., M.D. and Robert W. Virtue, M.D., Ph.D., Denver

Psychiatric Disorders and Function in Adolescents with d-Transposition of the Great Arteries

David R. DeMaso, MD^{1,2,3,4}, Madelyn Labella, BA¹, George Alexander Taylor, BA¹, Peter W. Forbes, MA¹, Christian Stopp, MS², David C. Bellinger, PhD, MSc^{1,2,3,5,6}, Michael J. Rivkin, MD^{1,6,7}, David Wypij, PhD^{2,3,4,8}, and Jane W. Newburger, MD, MPH^{2,4}

Neurodevelopmental Abnormalities and Congenital Heart Disease Insights Into Altered Brain Maturation

Paul D. Morton, Nobuyuki Ishibashi, Richard A. Jonas

Perioperative Stroke in Infants Undergoing Open Heart Operations for Congenital Heart Disease

Jodi Chen, MD, Robert A. Zimmerman, MD, Gail P. Jarvik, MD, PhD, Alex S. Nord, BA, Robert R. Clancy, MD, Gil Wernovsky, MD, Lisa M. Montenegro, MD, Diane M. Hartman, RN, CCRC, Susan C. Nicolson, MD, Thomas L. Spray, MD, J. William Gaynor, MD, and Rebecca Ichord, MD

A COMPARISON OF THE PERIOPERATIVE NEUROLOGIC EFFECTS OF HYPOTHERMIC CIRCULATORY ARREST VERSUS LOW-FLOW CARDIOPULMONARY BYPASS IN INFANT HEART SURGERY

JANE W. NEWBURGER, M.D., M.P.H., RICHARD A. JONAS, M.D., GIL WERNOVSKY, M.D., DAVID WYPJ, PH.D., PAUL R. HICKEY, M.D., KARL C.K. KUBAN, M.D., S.M., DAVID M. FARRELL, M.A., C.C.P., GREGORY L. HOLMES, M.D., SANDRA L. HELMERS, M.D., JULES CONSTANTINOU, F.R.A.C.P., ENRIQUE CARRAZANA, M.D., JOHN K. BARLOW, M.D.,* AMY Z. WALSH, R.N., B.S.N., KRISTIN C. LUCIUS, R.N., M.S., JANE C. SHARE, M.D., DAVID L. WISSEL, M.D., FRANK L. HANLEY, M.D., JOHN E. MAYER, JR., M.D., ALDO R. CASTANEDA, M.D., AND JAMES H. WARE, PH.D.

Intellectual Functioning in Children with Congenital Heart Defects Treated with Surgery or by Catheter Interventions

Carmen Ryberg*, Jan Sunnevigdt*, Maria Thorson* and Malin Broberg*

*Pediatrics Unit, Department of Pediatric Cardiology, The Queen Silvia Children's Hospital, Engeströmsvägen 1, S-413 45 Göteborg, Sweden; **Department of Pediatrics, The Queen Silvia Children's Hospital, Engeströmsvägen 1, S-413 45 Göteborg, Sweden; ***Department of Pediatrics, University of Gothenburg, Gothenburg, Sweden

Intellectual Functioning in Children with Congenital Heart Defects Treated with Surgery or by Catheter Interventions

Carmen Ryberg*, Jan Sunnevigdt*, Maria Thorson* and Malin Broberg*

New White Matter Brain Injury after Infant Heart Surgery is Associated with Diagnostic Group and the Use of Circulatory Arrest

John Beca, Julia K. Gunn, Lee Coleman, Aytan Hope, Peter W. Reed, Rodney W. Hunt, Kirsten Finucane, Christian Brizard, Brianna Dance and Lara S. Shekerdemian

Report of the Pediatric Heart Network and National Heart, Lung, and Blood Institute Working Group on the Perioperative Management of Congenital Heart Disease

Jonathan R. Kaltman, Dean B. Andropoulos, Paul A. Checchia, J. William Gaynor, Timothy M. Hoffman, Peter C. Laussen, Richard G. Ohye, Gail D. Pearson, Frank Pigula, James Tweddell, Gil Wernovsky and Pedro del Nido

Multimodality Neuromonitoring for Pediatric Cardiac Surgery: Our Approach and a Critical Appraisal of the Available Evidence

Joseph B. Clark, MD^{1,2}, Mollie L. Barnes, CNIM, Aislinn Under, PhD^{2,3}, and John L. Myers, MD^{1,2}

Neurodevelopmental Outcomes After Open Heart Operations Before 3 Months of Age

Renée Sananes, PhD, Cedric Manlihot, BS, Edmond Kelly, MD, Lisa K. Hornberger, MD, William G. Williams, MD, Daune MacGregor, MD, Raymond Buncic, MD, and Brian W. McCrindle, MD, MPH

Brain magnetic resonance imaging abnormalities after the Norwood procedure using regional cerebral perfusion

Catherine L. Dent, MD,* James P. Spaeth, MD,¹ Blaise V. Jones, MD,* Steven M. Schwartz, MD,* Tracy A. Glauser, MD,² Barbara Hallinan, MD,² Jeffrey M. Pearl, MD,² Philip R. Khoury, MS,^{2,4} and C. Dean Kurth, MD²

Cerebral oxygen metabolism in neonates with congenital heart disease quantified by MRI and optics

Varsha Jain^{1,2}, Erin M Buckley^{2,3,7}, Daniel J Licht², Jennifer M Lynch², Peter J Schwab², Maryam Y Naim⁴, Natasha A Lavin⁴, Susan C Nicolson⁴, Lisa M Montenegro⁴, Arjun G Yodh³ and Felix W Wehrli¹

Regional High-Flow Cerebral Perfusion Improves Both Cerebral and Somatic Tissue Oxygenation in Aortic Arch Repair

Kagami Miyaji, MD, PhD, Takashi Miyamoto, MD, PhD, Satoshi Kohira, CCP, Kei-ichi Itatani, MD, Takahiro Tomoyasu, MD, Nobuyuki Inoue, MD, and Kuniyoshi Ohara, MD, PhD

Increasing duration of circulatory arrest, but not antegrade cerebral perfusion, prolongs postoperative recovery after neonatal cardiac surgery

Selma O. Algra, MD,* Verena N. N. Kommamm, MD,² Ingeborg van der Tweel, PhD,² Antonius N. J. Schouten, MD,² Nicolaas J. G. Jansen, MD,² and Felix Haas, MD²

Protecting the Infant Brain During Cardiac Surgery: A Systematic Review

Jennifer C. Hirsch, MD, MS, Marshall L. Jacobs, MD, Dean Andropoulos, MD, Erle H. Austin, MD, Jeffrey P. Jacobs, MD, Daniel J. Licht, MD, Frank Pigula, MD, James S. Tweddell, MD, and J. William Gaynor, MD

Erythropoietin neuroprotection in neonatal cardiac surgery: A phase I/II safety and efficacy trial

Dean B. Andropoulos, MD, MHCM,^{a,b,c} Ken Brady, MD,^{a,b,c} Ronald B. Easley, MD,^{a,b,c} Heather A. Dickerson, MD,^{b,c} Robert G. Voigt, MD,^{b,c} Lara S. Shekerdemian, MB, BS,^{b,b} Marcie R. Meador, BSN, MS, RN,^{a,b,c} Carol A. Eisenman, BSN, RN,^{a,b} Jill V. Hunter, MB, BS,^{a,c} Marie Turcich, BA, MA,^{b,b} Carlos Rivera, MD,^{b,c} Emmet D. McKenzie, MD,^{a,c} Jeffrey S. Heinle, MD,^{a,c} and Charles D. Fraser, Jr, MD^{b,c,d}

Non-invasive Assessment of Cerebral Blood Flow and Oxygen Metabolism in Neonates during Hypothermic Cardiopulmonary Bypass: Feasibility and Clinical Implications

AJ Block, BSc¹, PS McQuillen, MD², V Chau, MD¹, H Glass, MD^{3,4}, KJ Poskitt, MDCM², AJ Barkovich, MD^{4,5}, M Esch, BA³, W Soulikias, RN², A Azakie, MD⁶, A Campbell, MD², and SP Miller, MAS, MDCM^{2,4}

Perioperative cerebral oxygen saturation in neonates with hypoplastic left heart syndrome and childhood neurodevelopmental outcome

George M. Hoffman, MD,^{a,b} Cheryl L. Brosig, PhD,^{a,b,c} Kathleen A. Mussatto, BSN, PhD,^{a,c,d} James S. Tweddell, MD,^{a,b,c} and Nancy S. Ghanayem, MD^{b,b}

Temporal and Anatomic Risk Profile of Brain Injury With Neonatal Repair of Congenital Heart Defects

Patrick S. McQuillen, MD; A. James Barkovich, MD; Shannon E.G. Hamrick, MD; Marta Perez, BA; Phil Ward, MSc; David V. Glidden, PhD; Anthony Azakie, MD; Tom Karl, MD; Steven P. Miller, MD

Quality of Life of Children After Repair of Transposition of the Great Arteries

Erin L. Culbert, MD; David A. Ashburn, MD; Geraldine Cullen-Dean, RN, MN; Jay A. Joseph, MSc; William G. Williams, MD; Eugene H. Blackstone, MD; Brian W. McCrindle, MD, MPH; and the Congenital Heart Surgeons Society

A randomized clinical trial of regional cerebral perfusion versus deep hypothermic circulatory arrest: Outcomes for infants with functional single ventricle

Caren S. Goldberg, MD,* Edward L. Bove, MD,² Eric J. Devaney, MD,² Eileen Mollen, PhD,² Edward Schwartz, PhD,² Shauna Tindall, PhD,² Cheryl Nowak, RN,² John Charpie, MD,² Morton B. Brown, PhD,² Tom J. Kulik, MD,² and Richard G. Ohye, MD²

Early Developmental Outcome in Children With Hypoplastic Left Heart Syndrome and Related Anomalies The Single Ventricle Reconstruction Trial

Jane W. Newburger, MD, MPH, Lynn A. Sleeper, ScD; David C. Bellinger, PhD, MSc; Caren S. Goldberg, MD, MS; Sarah Tabbutt, MD, PhD; Minmin Lu, MS; Kathleen A. Mussatto, PhD, RN; Ismee A. Williams, MD, MS; Kathryn E. Gustafson, PhD; Seema Mittal, MD; Nancy Pike, RN, PhD; Erica Sood, PhD; William T. Mahle, MD; David S. Cooper, MD; Carolyn Dunbar-Masterson, BSN, RN; Catherine Dent Krawczewski, MD; Alan Lewis, MD; Shaji C. Menon, MD; Victoria L. Pemberton, RNC, MS; Chitra Ravishanker, MD; Teresa W. Atz, MSN; Richard G. Ohye, MD; J. William Gaynor, MD, for the Pediatric Heart Network Investigators

Organizational topology of brain and its relationship to ADHD in adolescents with d-transposition of the great arteries

Vincent J. Schmithorst^{1,1}, Ashok Panigrahy^{1,2,3,4,1}, J. William Gaynor², Christopher G. Watson^{6,7}, Vince Lee², David C. Bellinger², Michael J. Rivkin^{4,8,9,10,11} & Jane W. Newburger^{1,12,1}

Usefulness of Regional Cerebral Perfusion Combined With Coronary Perfusion During One-Stage Total Repair of Aortic Arch Anomaly

Hong-Gook Lim, MD, PhD, Woong-Han Kim, MD, PhD, Chun-Soo Park, MD, Eui-Suk Chung, MD, Chang-Ha Lee, MD, PhD, Jeong Ryul Lee, MD, PhD, and Yong Jin Kim, MD, PhD

Randomized trial of hematocrit 25% versus 35% during hypothermic cardiopulmonary bypass in infant heart surgery

Jane W. Newburger, MD, MPH,^{a,b} Richard A. Jonas, MD,^{b,c} Janet Soul, MD,^{c,d} Barry D. Kussman, MBBCh,^{b,d} David C. Bellinger, PhD, MSc,^{c,d} Peter C. Laussen, MD,^{a,d} Richard Robertson, MD,^{a,b} John E. Mayer Jr, MD,^{b,c} Pedro J. del Nido, MD,^{b,c} Emile A. Bacha, MD,^{b,c} Joseph M. Forbes, MD,^{b,c} Frank Pigula, MD,^b Stephen J. Roth, MD, MPH,^a Karen J. Visconti, PhD,^b Adre J. du Plessis, MBChB, MPH,^{c,d} David M. Farrell, MA, CCP,^b Ellen McGrath, RN,^a Leonard A. Rappaport, MD,^b and David Wypij, PhD^{a,b,1}

The quest to optimize neurodevelopmental outcomes in neonatal arch reconstruction: The perfusion techniques we use and why we believe in them

Richard G. Ohye, MD,* Caren S. Goldberg, MD, MS,² Janet Donohue, MPH, MS,² Jennifer C. Hirsch, MD, MS,² Michael G. Gies, MD,² Marshall L. Jacobs, MD,² and James G. Gurney, PhD,¹ for the Michigan Congenital Heart Outcomes Research and Discovery Investigators

Principles of Antegrade Cerebral Perfusion During Arch Reconstruction in Newborns/Infants

Charles D. Fraser Jr, M.D. and Chief, Congenital Heart Surgery, Texas Children's Hospital, Professor of Surgery and Pediatrics, Michael E. DeBakey Department of Surgery, Baylor College of Medicine, Houston, Texas

Dean B. Andropoulos, M.D., M.H.C.M., Chief of Anesthesiology, Texas Children's Hospital, Professor of Anesthesiology and Pediatrics, Baylor College of Medicine, Houston, Texas

Behaviour at eight years in children with surgically corrected transposition: The Boston Circulatory Arrest Trial*

David C. Bellinger,¹ Jane W. Newburger,^{2,3} David Wypij,^{2,4} Karl C. K. Kuban,¹ Adre J. duPlessis,¹ Leonard A. Rappaport^{2,5}

Impaired Global and Regional Cerebral Perfusion in Newborns with Complex Congenital Heart Disease

Usha D. Nagaraj, MD^{1,2}, Iordanis E. Evangelou, DPhil^{3,4}, Mary T. Donofrio, MD^{4,5,6}, L. Gilbert Vezina, MD^{3,4}, Robert McCarter, PhD^{7,7}, Adre J. du Plessis, MD^{6,8}, and Catherine Limperopoulos, PhD^{3,4,8}

Cerebral oxygen metabolism in neonates with congenital heart disease quantified by MRI and optics

Varsha Jain^{1,2}, Erin M Buckley^{2,3,7}, Daniel J Licht², Jennifer M Lynch², Peter J Schwab², Maryam Y Naim⁴, Natasha A Lavin⁴, Susan C Nicolson⁴, Lisa M Montenegro⁴, Arjun G Yodh³ and Felix W Wehrli¹

Regional Low-Flow Perfusion Versus Circulatory Arrest in Neonates: One-Year Neurodevelopmental Outcome

Karen J. Visconti, PhD, David Rimmer, MS, Kimberlee Gauvreau, ScD, Pedro del Nido, MD, John E. Mayer, Jr, MD, Ikuo Hagino, MD, and Frank A. Pigula, MD

Neurodevelopmental Outcomes After Regional Cerebral Perfusion With Neuromonitoring for Neonatal Aortic Arch Reconstruction

Dean B. Andropoulos, MD, R. Blaine Easley, MD, Ken Brady, MD, E. Dean McKenzie, MD, Jeffrey S. Heinle, MD, Heather A. Dickerson, MD, Lara S. Shekerdemian, MBChB, Marcie Meador, RN, MS, Carol Eisenman, RN, Jill V. Hunter, MBBS, Marie Turcich, MS, Robert G. Voigt, MD, and Charles D. Fraser, Jr, MD
Departments of Pediatrics, Anesthesiology, Surgery, and Radiology, Baylor College of Medicine, Houston, and Divisions of Pediatric Cardiovascular Anesthesiology, Congenital Heart Surgery, Pediatric Cardiology, Pediatric Intensive Care, Pediatric Neurology, and Developmental Pediatrics, Texas Children's Hospital, Houston, Texas



Summary of **Validated** Improvements in Intraoperative CPB Management

Remember: "Absolute Cut-off Values Should Never Be Set for Continuous Variables"

1. Keep **Hematocrit** Higher rather than Lower

- Better closer to 35% rather than 25%

2. Minimize Duration of **Deep Hypothermic Circulatory Arrest** (if used)

- Threshold values (with current strategies) in the 35-45 minute range

3. Unknowns Persist

- **Should these be patient-specific? What are the effects of genetics, lesion, age?**
- **Steroids** - yes/no; when; how much; all patients or just some?
- **Alpha-stat vs pH stat**
- **Flow rates**
- **Temperature**
- **Regional Cerebral Perfusion**

- (Strength of *Opinions* Not Necessary Correlated with Strength of the *Data*)

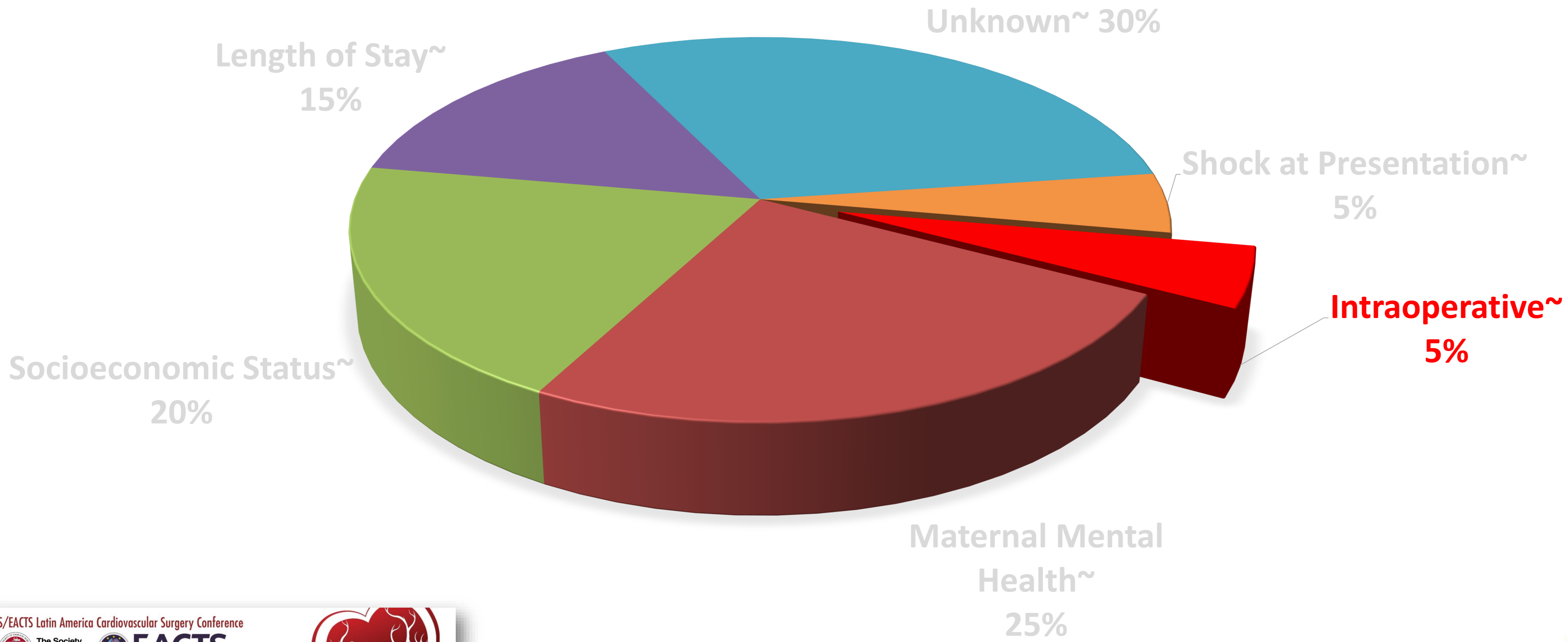
4. Seizures are a Bad Long-term Prognostic Sign

5. What Type of Monitoring, and What To Do With the Values?



The Effects of Mechanical Circulatory Support During Cardiac Surgery on the Brain

But How Much Does It Matter?:
% Variance in Scores Explained By:







The Journal of Thoracic and Cardiovascular Surgery

Volume 152, Issue 2, August 2016, Pages 482–489



Congenital: Hypoplastic left heart syndrome

Increasing cumulative exposure to volatile anesthetic agents is associated with poorer neurodevelopmental outcomes in children with hypoplastic left heart syndrome

Laura K. Diaz, MD^a, J. William Gaynor, MD^b, , , Shannon J. Koh, BA^b, Richard F. Ittenbach, PhD^c, Marsha Gerdes, PhD^d, Judy C. Bernbaum, MD^d, Elaine H. Zackai, MD^d, Robert R. Clancy, MD^d, Mohamed A. Rehman, MD^a, Jeffrey W. Pennington, BS^e, Nancy Burnham, MSN^b, Thomas L. Spray, MD^b, Susan C. Nicolson, MD^a

Increasing VAA exposure associated with significantly worse:

- Full Scale IQ
- Total language scores
- Executive function
- Memory
- Reading skills
- Math skills

–ALL $p < 0.05$



Increasing Fentanyl Exposure Associated with Significantly Worse:

Full Scale IQ

Total Language

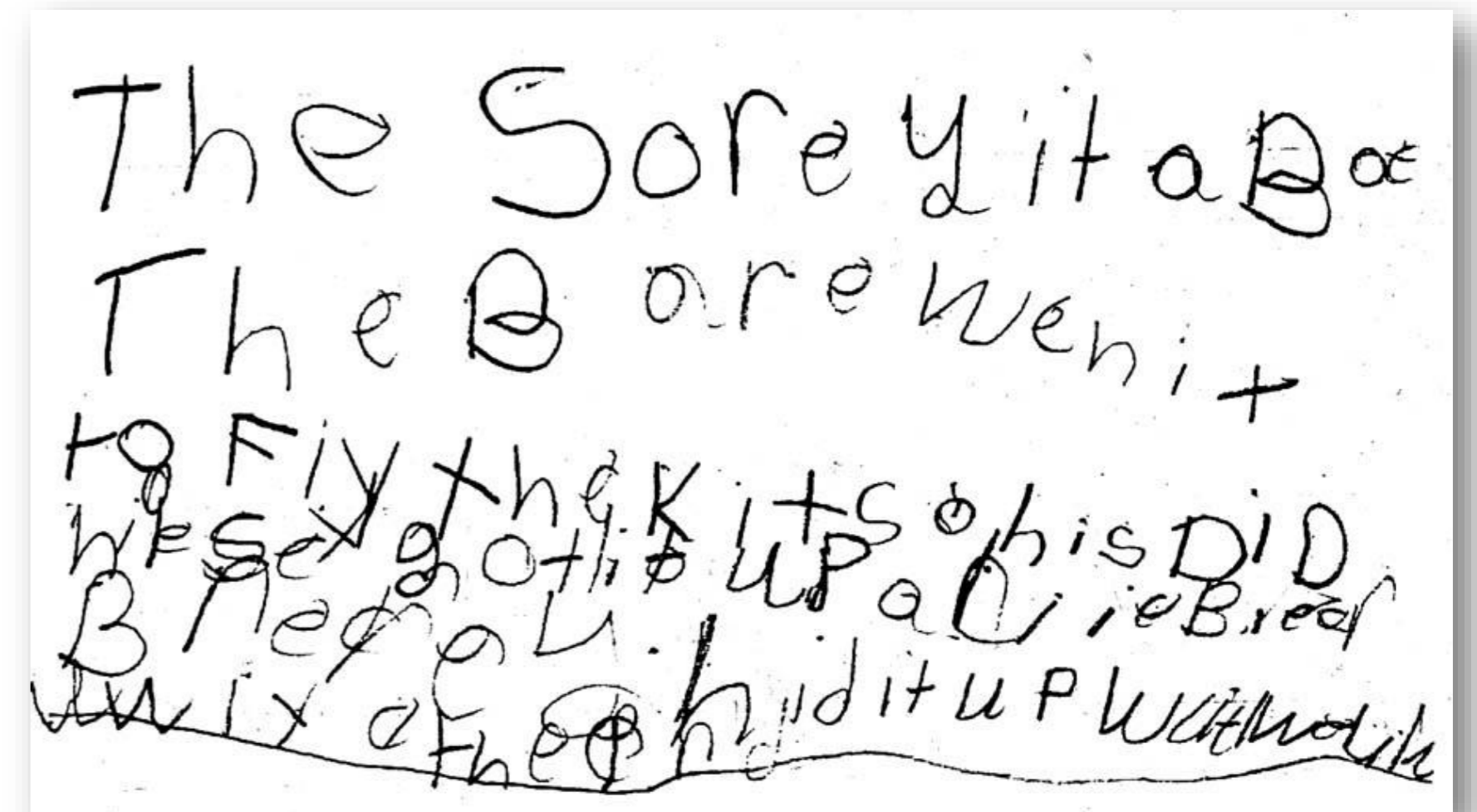
Processing speed

Memory

Fine motor skills

Math skills

- ***ALL $p < 0.05$***

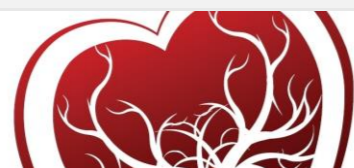
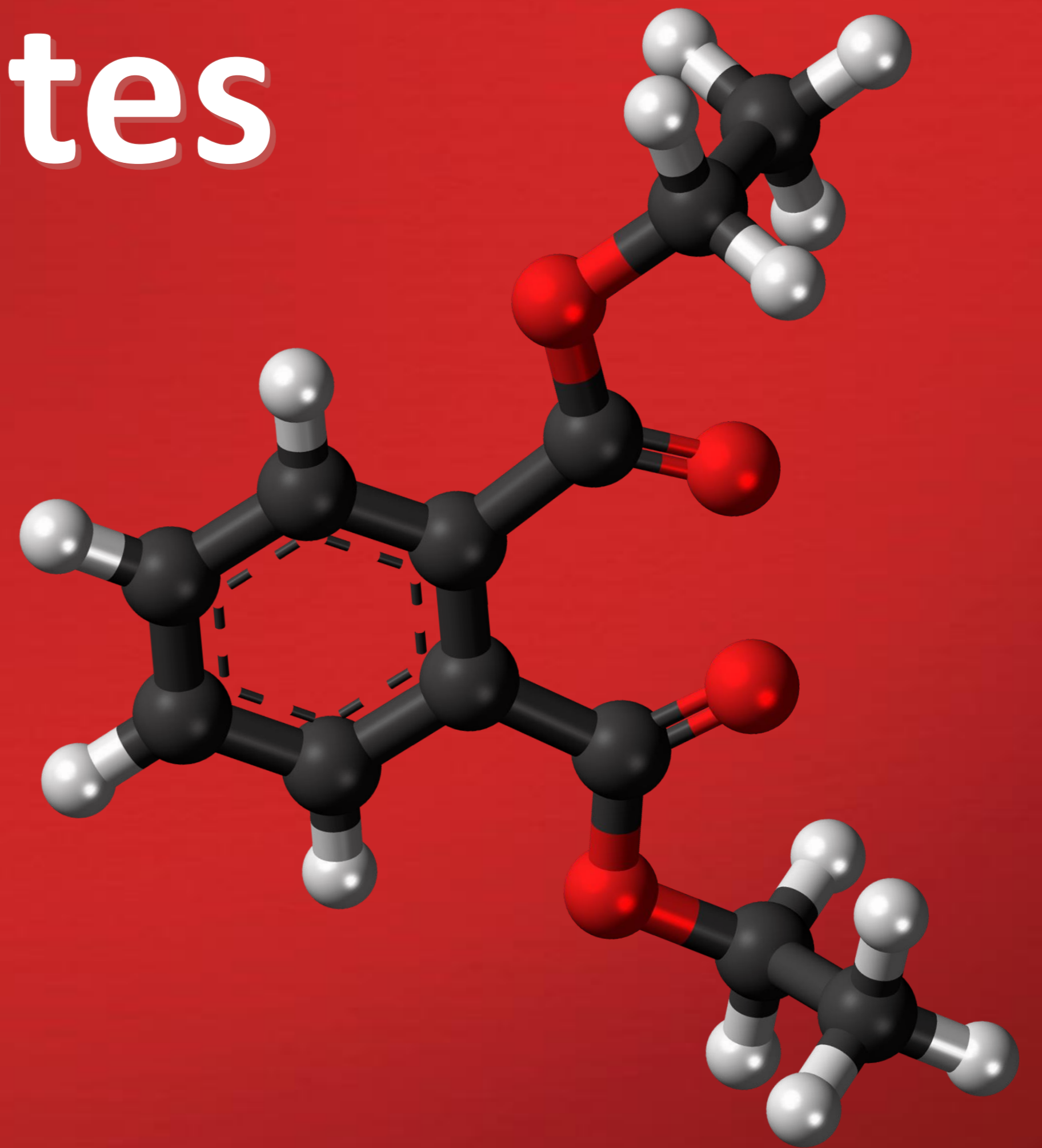
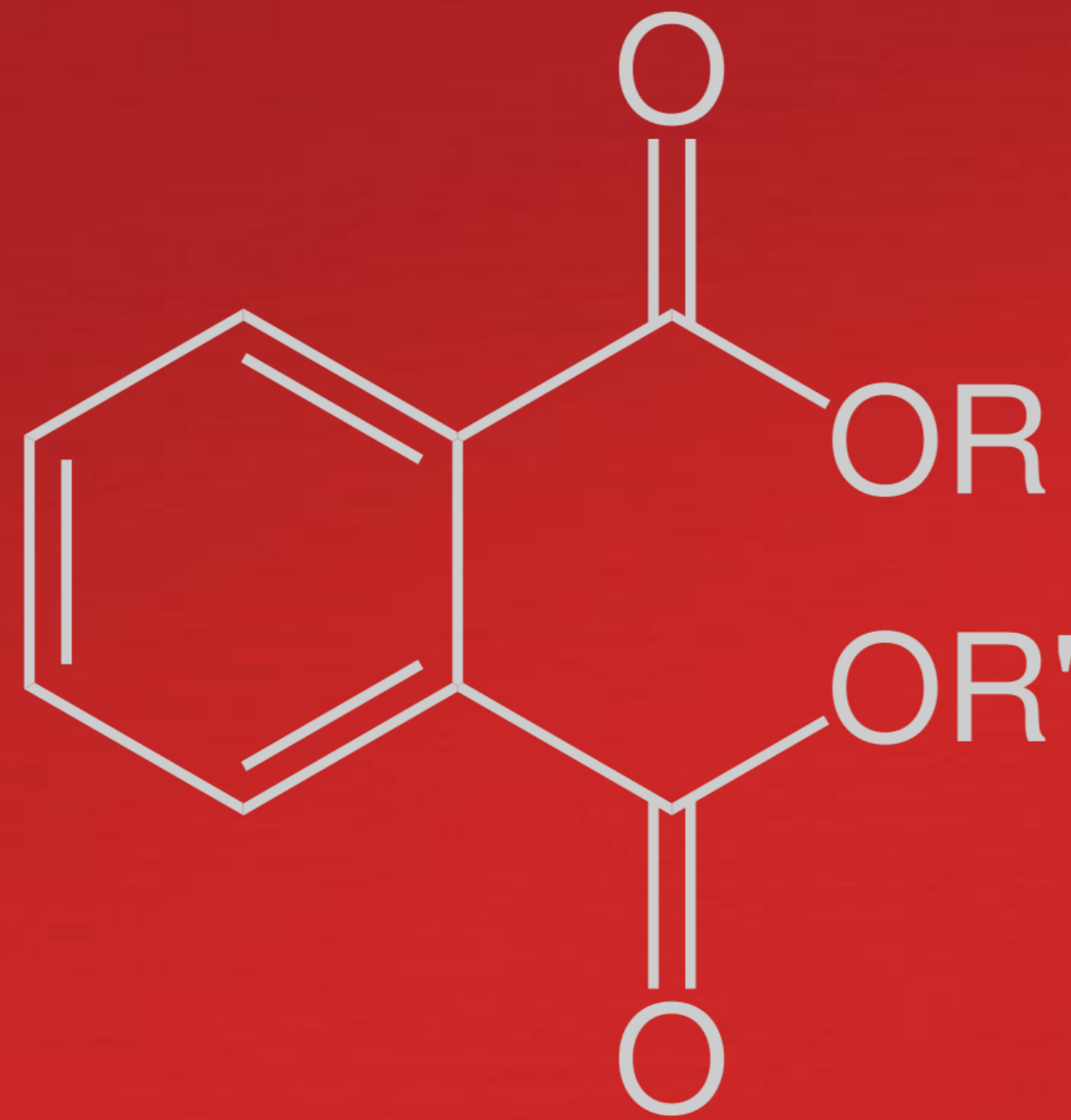


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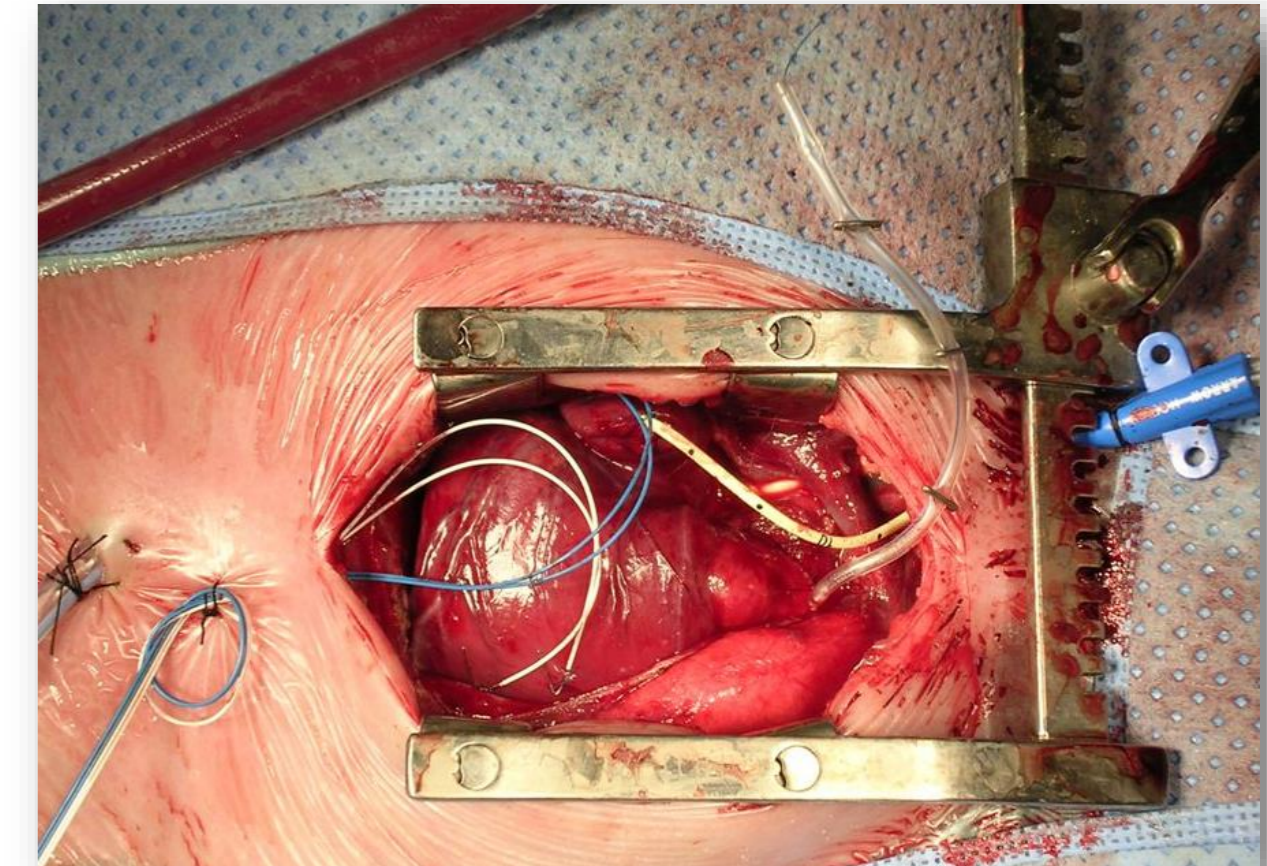
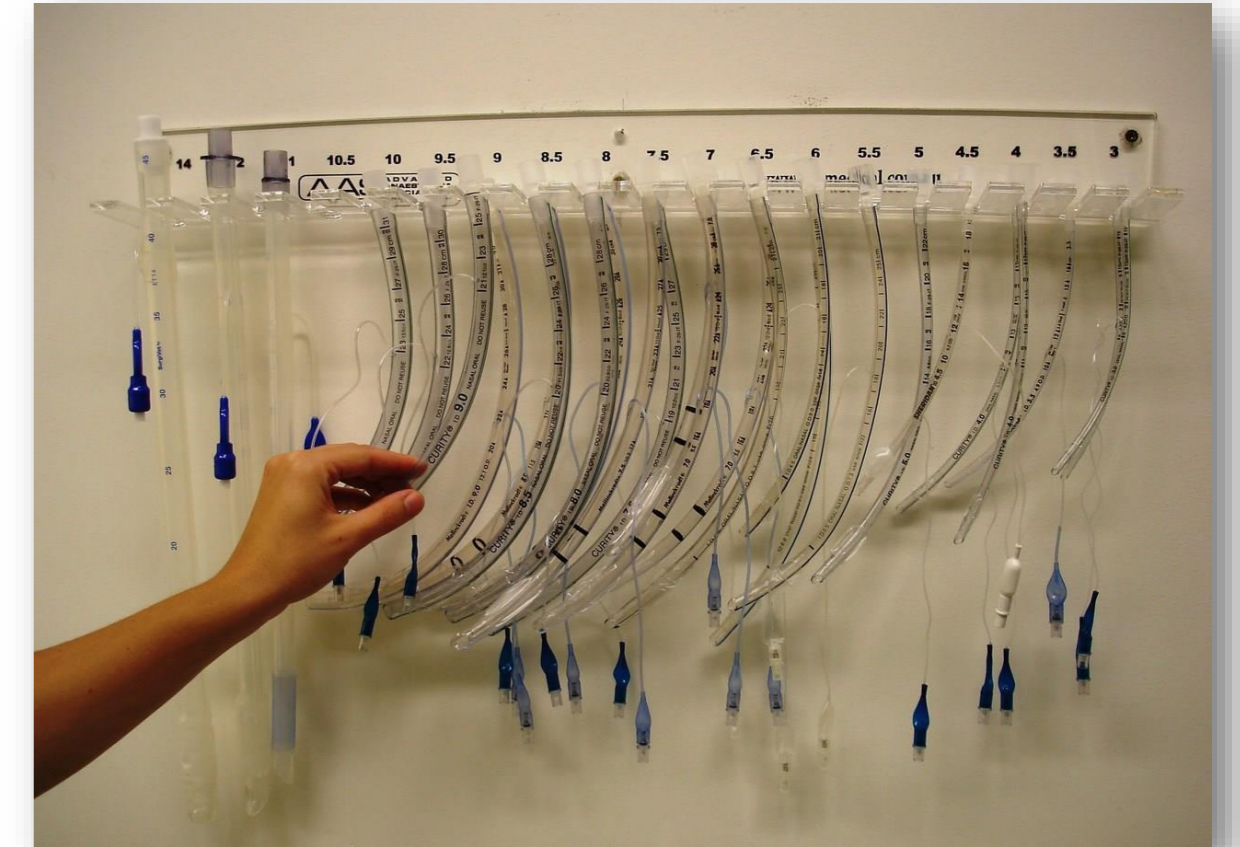
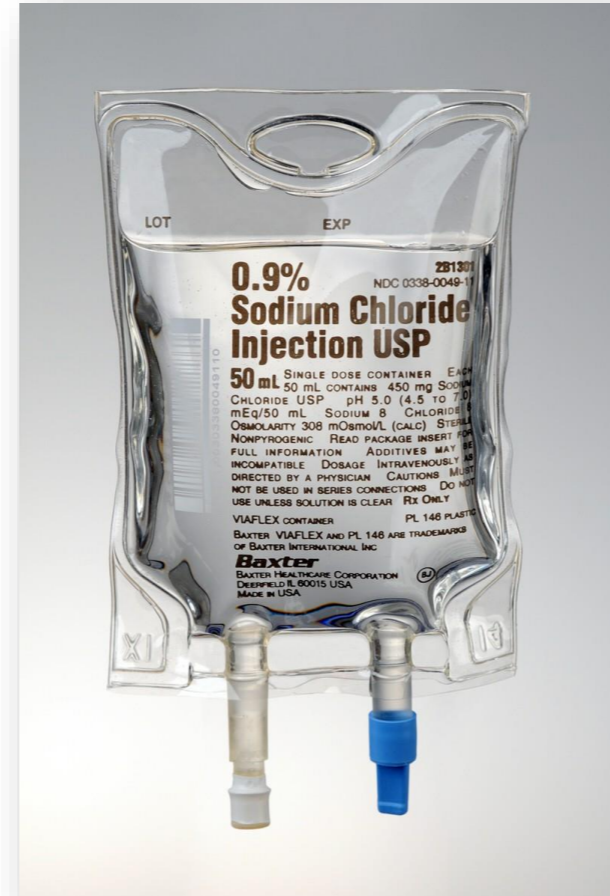
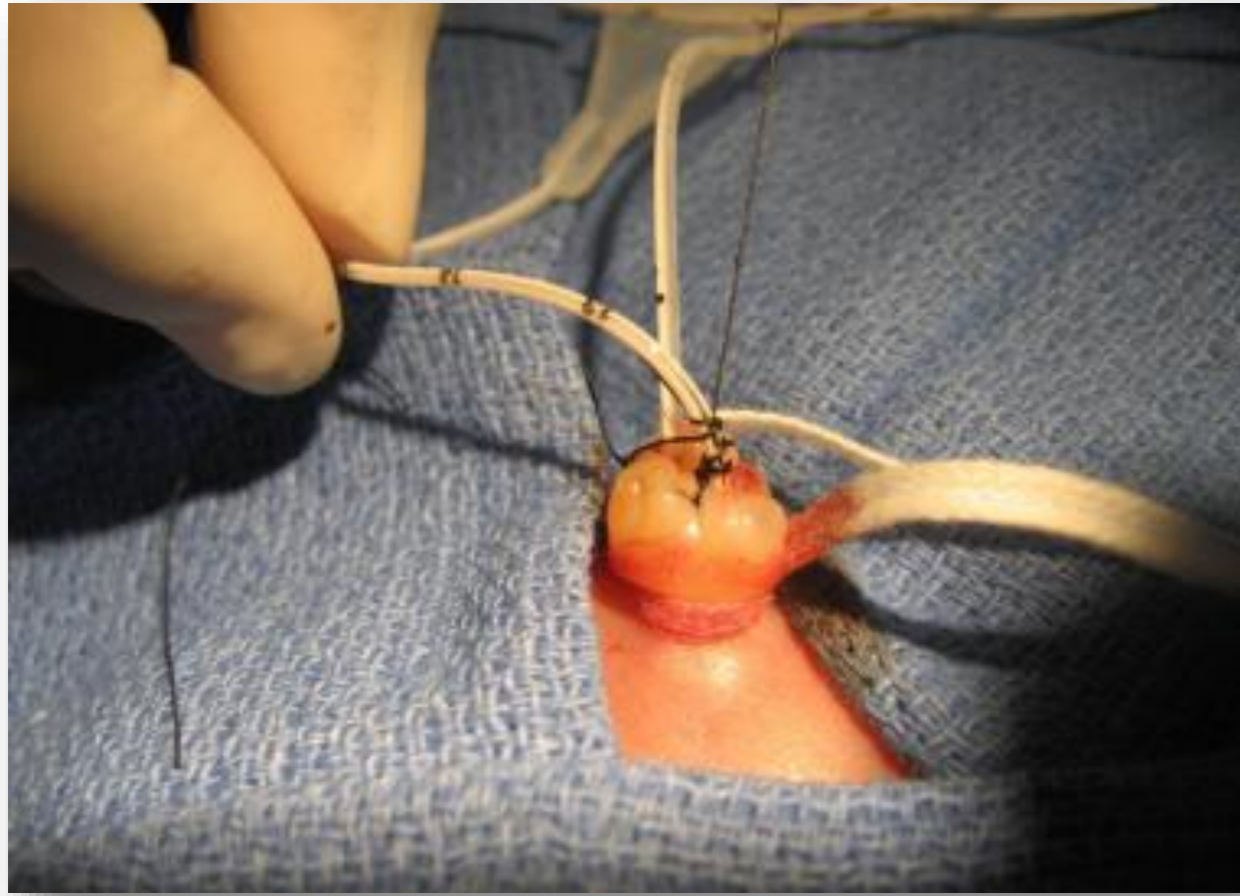
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What are other cumulative exposures during the hospital stay?

Phthalates



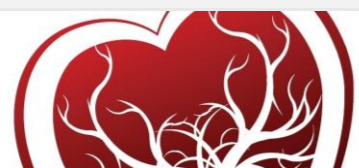
Phthalates



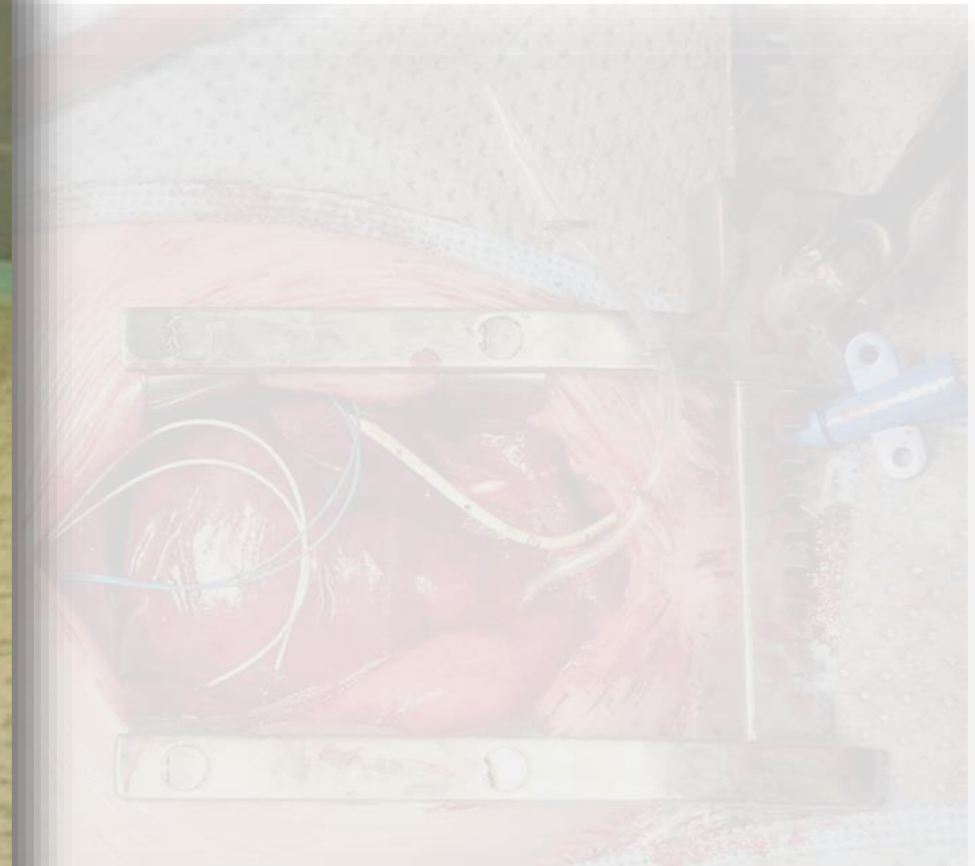
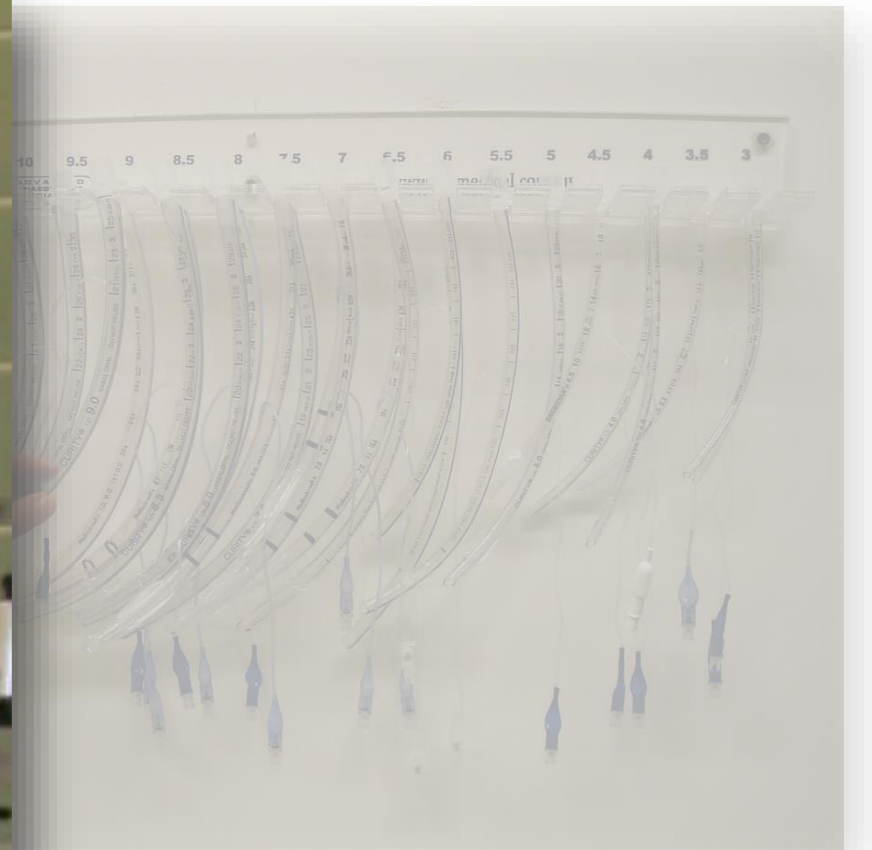
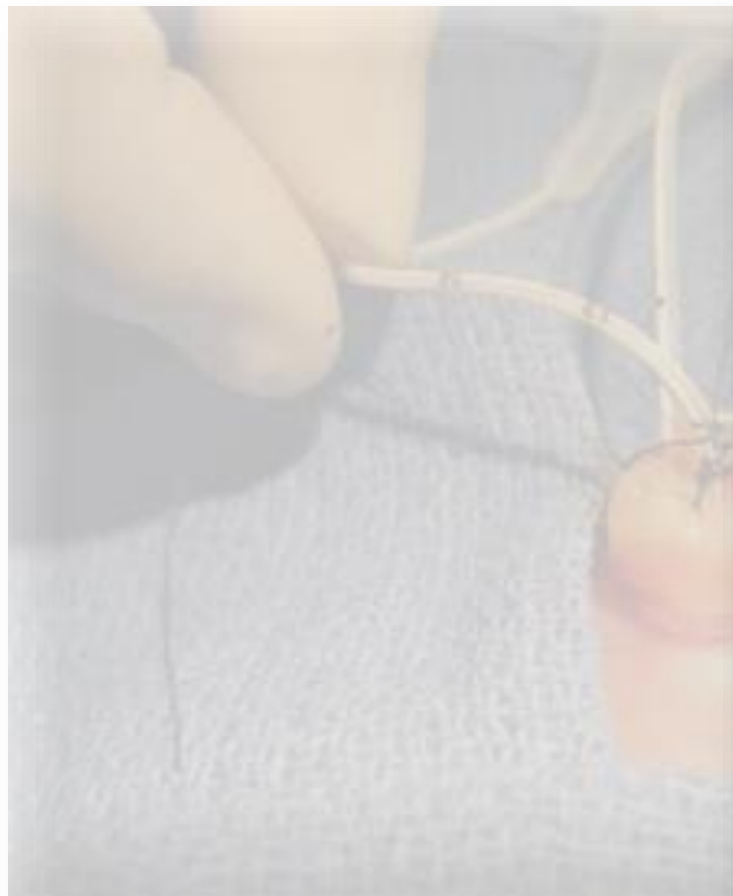
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STS/EACTS Latin America Cardiovascular Surgery Conference



Cardiopulmonary Bypass



Phthalates have been consistently implicated in learning difficulties & ADHD

Intensive Care Med (2016) 42:379–392
DOI 10.1007/s00134-015-4159-5

ORIGINAL



S. Verstraete
I. Vanhorebeek
A. Covaci
F. Güiza
G. Malarvannan
P. G. Jorens
G. Van den Berghe

Circulating phthalates during critical illness in children are associated with long-term attention deficit: a study of a development and a validation cohort

Phthalates have been consistently implicated in learning difficulties & ADHD

Plasma concentrations of phthalate (DEHP) metabolites in 100 healthy children and 449 children in PICU

DEHP metabolites undetectable in healthy children, elevated in PICU children upon PICU admission ($P < 0.001$).

DEHP metabolites decreased rapidly but remained **18 times higher until PICU discharge** ($P < 0.001$).

Taking “Stuff” Out As Soon As Possible

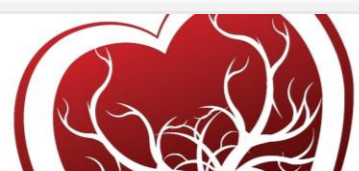
↓ *Short Term and Long Term Risk*

- **Phthalate Exposure Explained 1/2 of the Attention Deficit Disorder assessed 4 years after PICU Admission.**

The Most Modifiable Perioperative Factor For Improving Long-term Neurodevelopmental Outcomes is **Reducing Hospital Length of Stay**

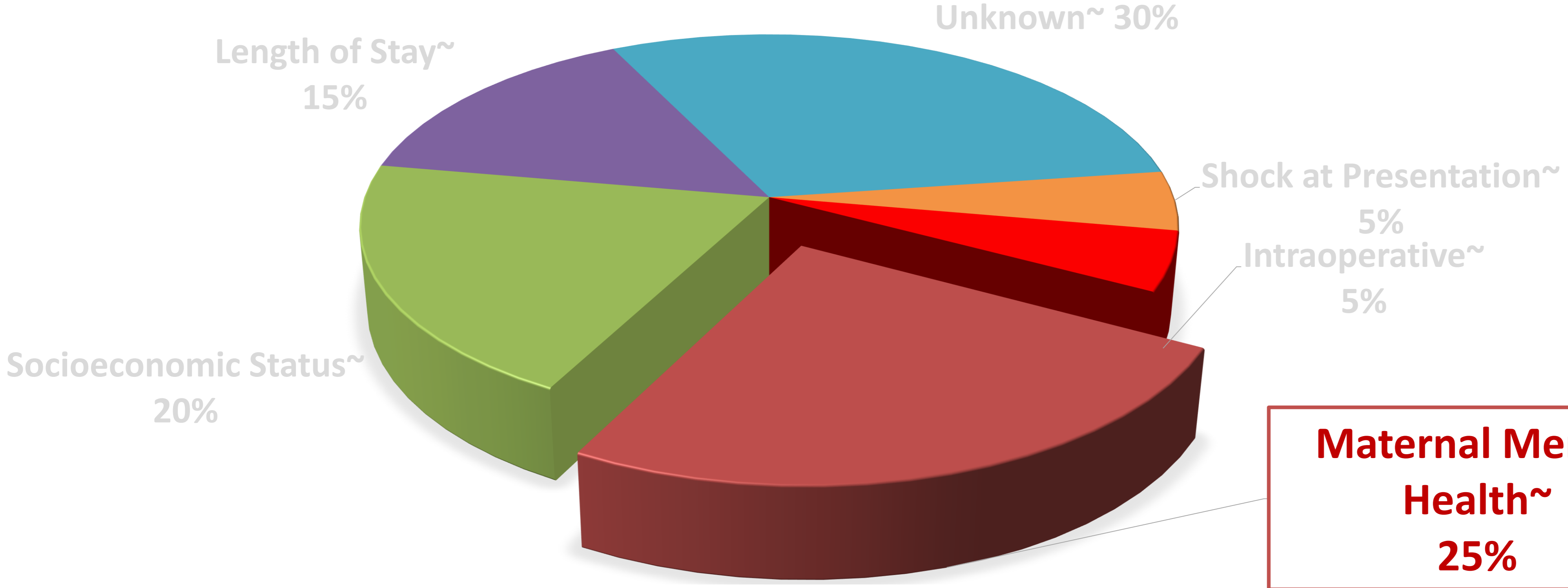
Longer LOS consistently associated with

- **Worse Neurodevelopmental Outcomes**
 - Multifactorial
 - Increased Sedation/Analgesia Usage
 - Toxin Exposure
- **Decreased Opportunity for Neurogenesis and Maternal Bonding**
- **Worse Parental Mental Health**



The Effects of Mechanical Circulatory Support During Cardiac Surgery on the Brain

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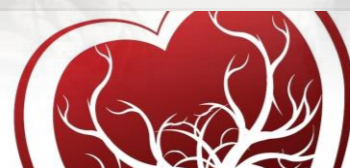
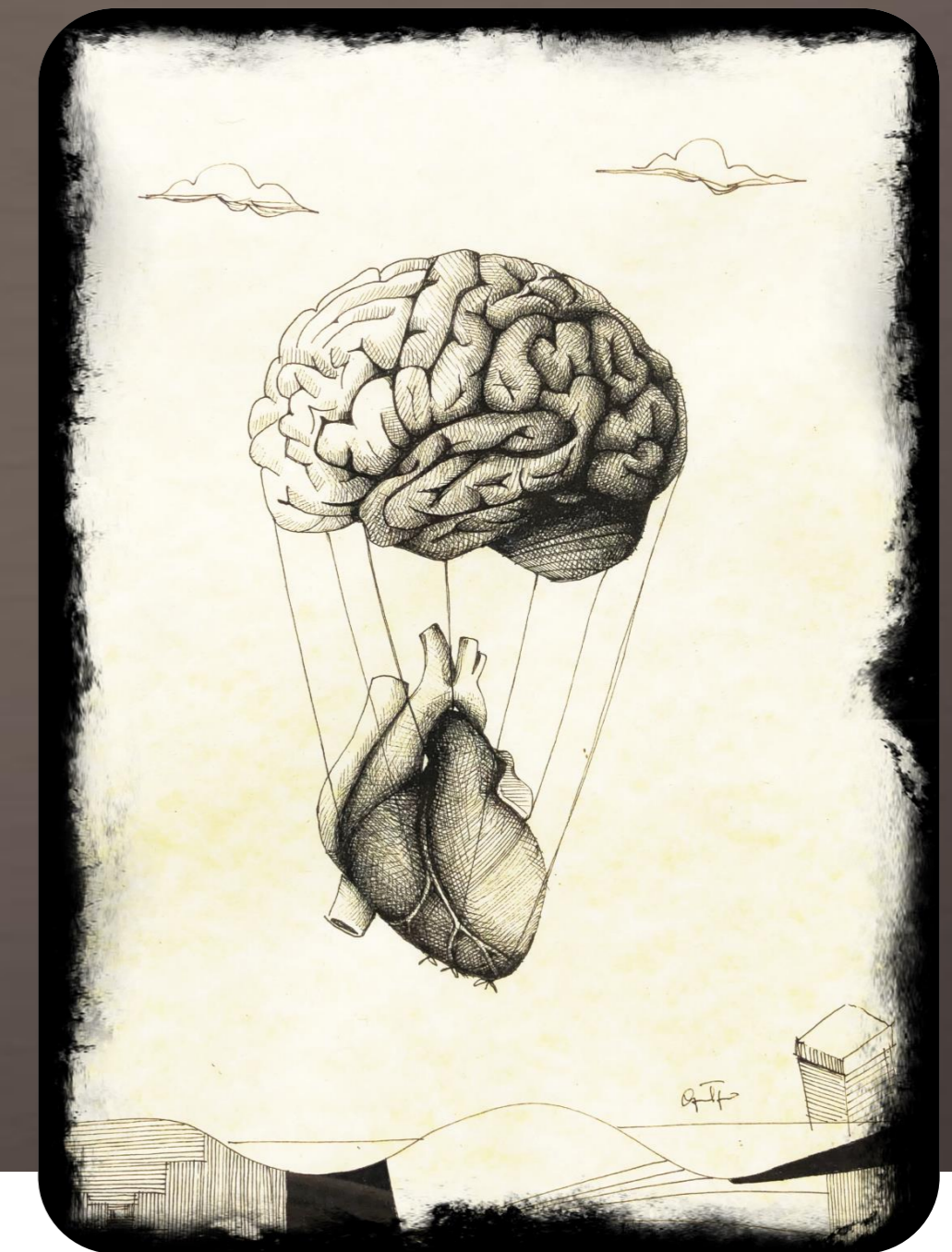
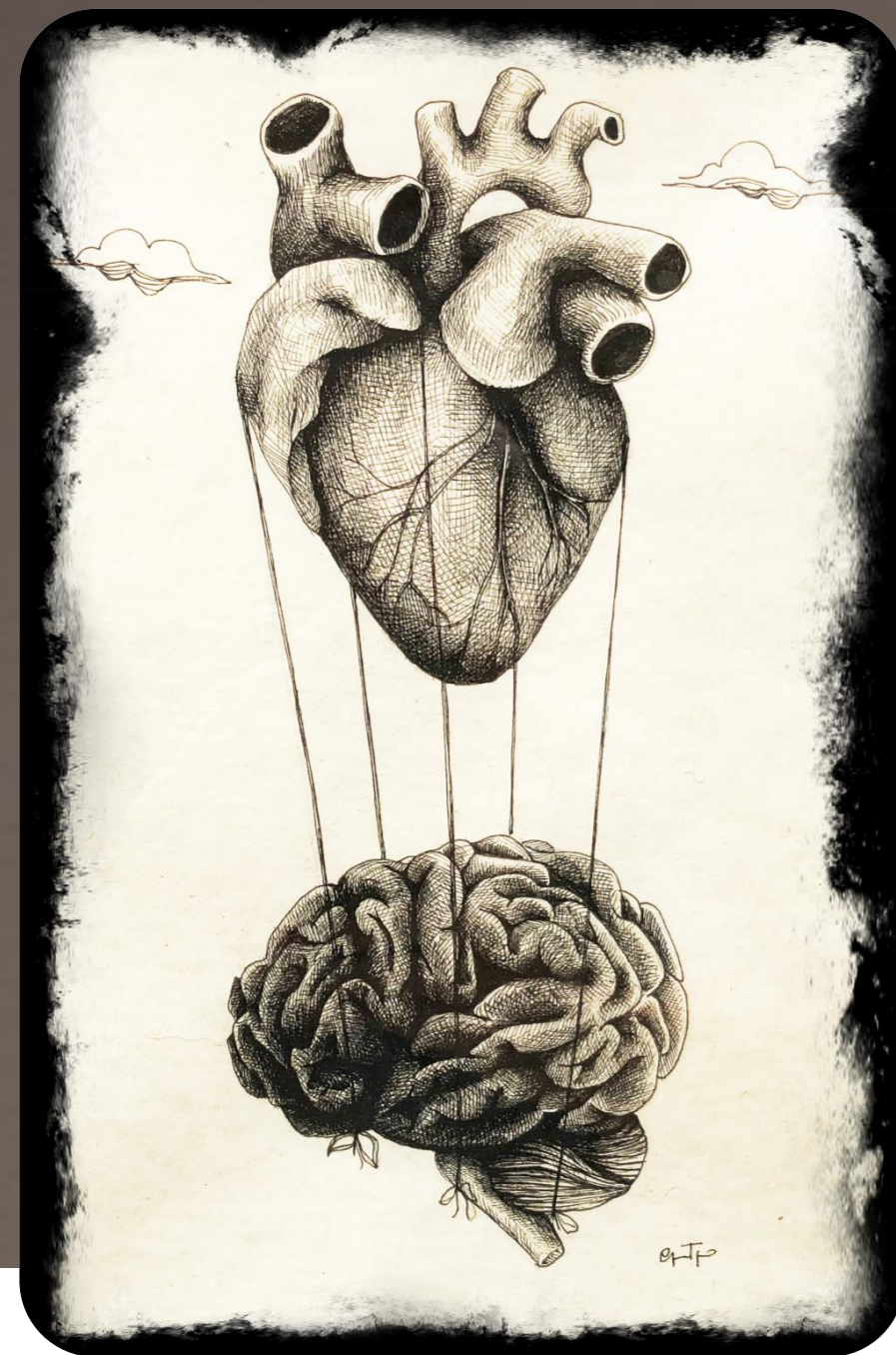
Maternal Mental Health ~ 25%



The Neurocardiac Critical Care Program

At Children's National Medical Center

Washington, DC, USA



NeuroCardiac Critical Care Program Leadership



Melissa Jones, MSN



Gil Wernovsky, MD



Sherrill Caprarola, MD



Neurologists

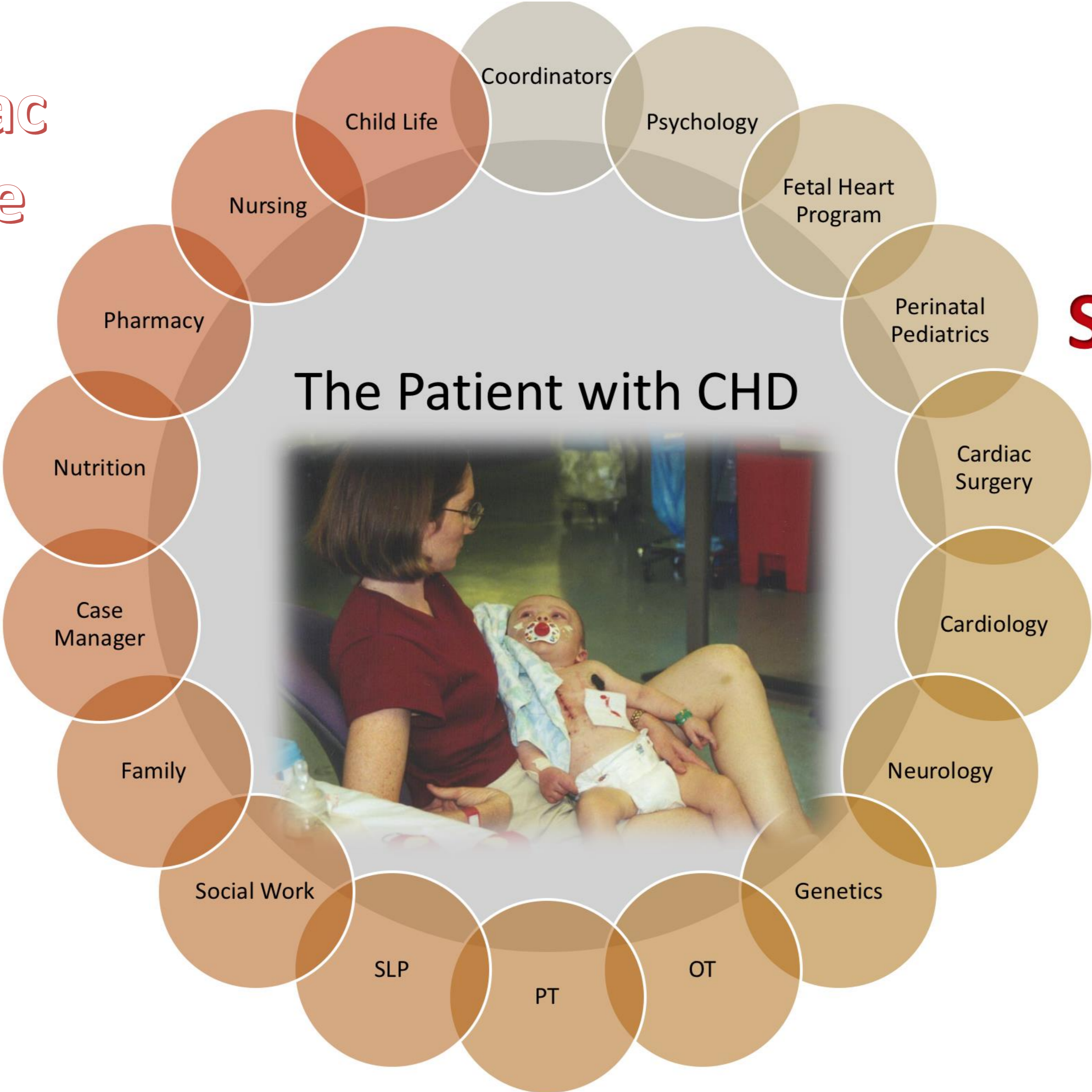


Jessica Carpenter, MD



Dana Harrar, MD

Neurocardiac Critical Care Program



Multiple Stakeholders



Children's NationalTM

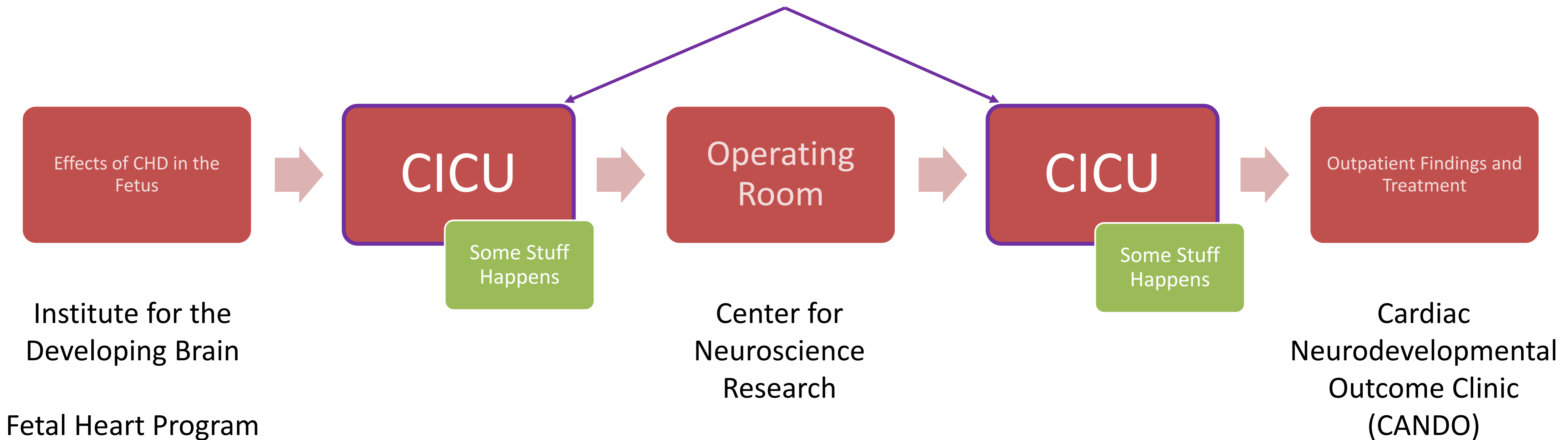
Heart Institute



Part of the Children's National Health System



NeuroCardiac Critical Care Program: Integral Part of a Comprehensive Approach to the Developing Brain in Children with Critical CHD



Neurocardiac Critical Care Program at Children's National

Six Pillars

Standardized Assessments

Monitoring and Surveillance

Neurodevelopmental Care

Neuroprotection

Extended Family Support

Immediately Available

Daily Sedation/Analgesia
Pre & Post-Op MRI
Newborn Screen
Hearing Screen

NIRS
EEG
Etiometry
Biomarkers
Cerebral Blood Flow

Breast Feeding
Bonding
Brain
Body

Phase I Clinical Trials
Seizure Treatment
Protocols

Mental Health Support
Case Manager
Mindfulness
Social Work
Child Life
Clergy
Yoga

Portable CT
Ultrasound
MRI
EEG

Critical Care
Neurologist

Routine Consults:

Neonatology
Neurology
Genetics
Physical Therapy
Occupational Therapy
Speech, Language, Feeding

Other Strategies:

Non-pharmacologic sedation
Music and Other Therapies
Minimize Noise, Light
Lactation Consultant
Prone Positioning
Skin-to-Skin Care
Physical therapy
Infant Massage

Telemedicine
Post-Discharge

Developmental
Intensivist



Summary

Risks for Brain Injury are Multiple and Cumulative

Treatment Must Be Multidisciplinary & Longitudinal

Research is Ongoing



Summary

*Further
Research
Timing of
Surgery*

*Further
Research*

Reduce Length of Stay

Family Support

Low Cerebral
Oxygen Delivery
Risk of
Paradoxical
Embolus

Effects on the
Brain From
Anesthesia
and CPB

Borderline
Hemodynamics
Prolonged or Too
Much Mechanical
Ventilation

Sedation
Analgesia
(*& Subsequent
Wean*)

Bland
Environment
Lack of Social
Stimulation
Noxious Stimuli
↑Noise

Poor Oral Motor
Coordination
Decreased
Feeding

Increased
Parental Stress
& Anxiety
Impacting
Outcome

Avoid Hyperventilation

*Wernovsky G and Licht D.
Peds Crit Care Med 2016;17(Aug):S232-S242*

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pediátrica y cardíaca

Visite WCPCS2021.org para más información.

— **Copresidentes:** Jeffrey P. Jacobs, MD • Gil Wernovsky, MD —



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Thank You!

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