Neonatology Hemodynamics Clinical Research (NHCR) Fellowship

Administrative Information
Name of Institution: McGill University
Duration: 1 or 2 years (this will depend on research project planned)
Number of positions: Maximum of 1 position (this will depend on funding available)
Type: Clinical Research Fellowship
Training Sites:
> McGill University Health Center – Montreal Children's Hospital
> Jewish General Hospital - NICU
> CHU Sainte-Justine (for elective only)

Parent Training Program: Neonatal-Perinatal Medicine
Fellowship Director: Gabriel Altit, Montreal Children's Hospital
Fellowship Coordinator: Tamara Slovick, Montreal Children's Hospital
Fellowship Training Committee Members: this fellowship will be under the direction of the RPC

1. Nina Nouraeyan, Neonatologist, JGH, Director, Neonatal Perinatal Medicine program and site supervisor at the JGH for the NHCR fellowship
2. Marc Beltempo, Neonatologist at MUHC, Research Coordinator, MUHC site supervisor for the NHCR fellowship; Program director of the Neonatal Perinatal Medicine Scholar Fellowship Program.
3. Elisabeth Hailu, Neonatologist at MUHC, MUHC NICU rotation coordinator
4. Michelle Ryan, Neonatologist at MUHC, Simulation coordinator
5. Victoria Bizgu, Neonatologist at JGH, JGH NICU rotation coordinator
6. Gabriel Altit, Neonatologist at MUHC, director of the Neonatal Hemodynamics Clinical Research Fellowship, mentorship program coordinator
7. External member: Samara Zavalkoff, Pediatric Intensive Care Unit, MCH

https://www.mcgill.ca/peds/education-training/pgme/programs/neonatology/fellowship
https://www.mcgill.ca/pgme/programs/fellowship-programs

Eligibility:

Eligible trainees must have completed a qualified program of residency in neonatal-perinatal medicine. (*Neonatology*). Residents who have obtained their MD in Québec and or/ who did a residency training in Québec in a contingent régulier or contingent particulier position can apply to the fellowship program via formations complémentaires only (https://www.mcgill.ca/pgme/admissions/formation-complementaire). The trainee has to be eligible to obtain a training card from *Collège des Médecins du Québec* (www.cmq.org) for neonatal-perinatal medicine. We will consider candidates who have a stronger interest in academic neonatology, as well as in neonatal hemodynamics. The trainee must be a Canadian citizen or eligible for a visa. Please contact us if questions arise regarding eligibility for the program (Tamara Slovick tamara.slovick2@muhc.mcgill.ca or Gabriel Altit – gabriel.altit@mcgill.ca).

Rationale and Mission:

Rationale: Neonatology is probably one of the youngest yet most advanced fields in Pediatrics. The numerous discoveries made through research has led to the most advanced and innovative treatments allowing preterm babies as young as 23 weeks gestation to survive and thrive. A graduating Neonatal Perinatal Medicine resident should be given the opportunity to obtain advanced training in neonatal echocardiography research methods, if he/she shows enthusiasm for neonatal cardiovascular research. In the recent years, the evaluation of cardiovascular growth and adaptation to extra-uterine life has led to many discoveries and improved the care of newborns admitted to the neonatal intensive care unit. Targeted neonatal echocardiography is an area of focused competence that is in the process of approval for certification through the Royal College of Physicians and Surgeons.

Neonatal hemodynamics research describes the use of echocardiography (conventional and advanced) for research in the cardiovascular performance of the neonate and of previous graduate of the NICU. Echocardiography has a central role in neonatal hemodynamics research. Echocardiography can be used to assess cardiac function (left and right sided), pulmonary pressures, intracardiac and extracardiac shunts (e.g. atrial septal defect, ventricular septal defect, patent ductus arteriosus), central line position, assessment of pericardial fluid and structural defects.

Training in neonatal echocardiography by neonatologists has been actively done in neonatal units in Australia, Canada, and across Europe. Multiple guidelines for Neonatologist-performed echocardiography training have been published (1-4). However, few programs offer training for neonatologists in neonatologist-performed echocardiography that follow these recommendations.

The trainee will participate in a longitudinal program of training centered around a scholar project in neonatal echocardiography/hemodynamics. This document describes this proposed training program.

This fellowship is designed to be flexible so as to accommodate interests and timelines of good research projects in neonatal echocardiography/hemodynamics.

Mission

The purpose of the McGill fellowship in Neonatal Hemodynamics Research is to provide the trainee with additional knowledge, skills and experience in neonatal hemodynamics needed to begin a potential career as an independent investigator using neonatal echocardiography and other tools for hemodynamic assessment. Indeed, the Neonatal Hemodynamics Clinical Research training program aims to teach the skills of cardiac ultrasound, provide an in depth understanding of cardiac physiology and to integrate both in the application of a neonatal research project. The training neonatologist will understand the scope of neonatal hemodynamics practice and its limitations. Specific training objectives are described in the curriculum.

Fellowship Objectives
A summary list of Neonatal Hemodynamics Clinical Research core knowledge areas includes:
Proficient practice in Neonatal Hemodynamics Clinical Research requires skills that include the ability to:
- Develop a complete understanding of neonatal cardiovascular physiology, anatomy and hemodynamics in the context of various neonatal pathological conditions and during their development
- Understand the physics of ultrasound, the limitation of the technique, the standardization of measures, the functioning of the echocardiography machine and of the software for analysis
- Understand the modalities for saving echocardiography images and ECG signals
- Apply all the necessary echocardiography views in the context of a research question in the neonatal period.
- Understand the principles of two-dimensional, Doppler (blood and tissue), M-mode and 3D imaging.
- Understand the meaning of echocardiography measurements.
- Appropriately calculate indices of function, pulmonary pressures and structural dimensions.
- Interpret echocardiographic hemodynamic indices in the context of an infant's presentation
- Standardize the approach to cardiac imaging, data extraction and data interpretation
- Develop a research question centered on a neonatal hemodynamics topic and using echocardiography as a tool for analysis
- Train in the methods of clinical research, including learning basic epidemiologic and biostatistical methods for a neonatal hemodynamics research project.
- Implement one or more clinical neonatal hemodynamics research projects, leading to the analysis, interpretation, and presentation of research data.
- Clinical training represents 25%, and academic /research training 75% of the fellowship.

Medical Expert:
A. **Exercise the role of a consultant**:
   a. Understand the physical properties of ultrasound waves and the technical and safety requirements for its use
   b. Appropriate understanding of cardiac anatomy (normal and abnormal), variants, and cardiovascular physiology in the context of neonatal transition
   c. Understand the normal and disordered neonatal circulatory transition
   d. Acquire knowledge on echocardiography indices and normative values of myocardial function, pulmonary and systemic blood flow, organ and tissue perfusion. Approach the systematic manner of extraction of data from echocardiography images.
   e. Understand the pathophysiology of pulmonary hypertension, cardiac failure, patent ductus arteriosus, high output cardiac failure, and shock in the neonatal population, and their tailored management

    f. Acquired the necessary views for line placement and recognition of a tamponade (assessment of severity of a pericardial effusion)

B. **Share knowledge of the basic and clinical sciences:** during the context of an echocardiography towards patients and medical health teams.

C. **Teach and supervise (in a graded appropriate level):**
    a. Appropriate use and performance of procedural skills, both diagnostic and therapeutic
    b. The coordination of transport of ill newborns
    c. Effective coordination of discharge and follow-up of NICU patients.
    d. Appropriate consultation from other health professionals, and recognition of limits of one's expertise:
    e. The pathophysiology and management of neonatal hemodynamic pathologies.

Communicator:
Teach and supervise, in a graded appropriate level:
A. Effective therapeutic relationships with families of ill newborns characterized by understanding, trust, respect, honesty, and empathy
B. Effective collection and synthesis of relevant information and perspectives, involving parents, families, colleagues, and other professionals
C. Conveying relevant information and explanations to families, colleagues, and other professionals
D. Provision of leadership in developing a common understanding on issues, problems, and plans with patients, families, colleagues, and other professionals to develop a shared plan of care

Collaborator:
Teach and supervise, in a graded appropriate level:
A. Effective and appropriate participation in an interprofessional health care team
B. Effective prevention, negotiation, and resolution of interprofessional conflict

Leader:
Teach and supervise, in a graded appropriate level:
A. Contribution to the effectiveness of the NICU activities
B. Teach and mentor effective time management principles
C. Appropriate allocation of finite health care resources

Health Advocate:
A. Teach and mentor approach to responding to individual patient and family health needs and concerns as part of patient care
B. Teach and supervise identification of determinants of health and subsequent health needs for the communities and populations under one's care
C. Teach and supervise responding to health needs of patient populations under one's care

<u>Scholar:</u>
1. **Maintain and enhance professional – research activities through ongoing learning**
   a. Demonstrate knowledge of the principles of maintenance of competence in research
      i. Describe the requirements of the maintenance of Certification Program of the Royal College of Physician and Surgeons of Canada
      ii. Describe the principles of continuing professional development
   b. Execute strategies for implementing a personal knowledge management system
   c. Recognize and reflect on research learning issues in practice
   d. Recognize and correct deficits in research knowledge through targeted learning
      i. Pose an appropriate research question
      ii. Access and interpret the relevant evidence
      iii. Integrate new learning into practice
      iv. Evaluate the impact of any change in research practice
      v. Document the research learning process
      vi. Formulate relevant personal research earning projects
   e. Conduct personal practice audits
2. **Critically evaluate scientific information and its sources and apply this appropriately to** research **practice decisions**
   a. Describe the principles of critical appraisal
   b. Critically appraise retrieved evidence in order to address a clinical research question
   c. Integrate critical appraisal conclusions into research
3. **Proficient in facilitating the learning of patients, families, students, residents, other health professionals, the public, and others in** research related problems
   a. Describe principles of learning relevant to research
      i. Select teaching strategies for patient and health care professional education based on the principles of research
   b. Identify collaboratively the learning needs and desired learning outcomes of others working on his/her research projects
   c. Select effective teaching strategies and content to facilitate others learning
   d. Deliver effective lectures or presentations
   e. Assess and reflect on teaching encounters
   f. Provide effective feedback
      i. Assess the knowledge, skills, and competence of junior research learners
      ii. Conduct debriefing sessions as a teaching and reflective tool following difficult resuscitations or incidents
   g. Describe the principles of ethics with respect to research

4. **Contribute and complete the development, dissemination and translation of new knowledge and practices**
   a. Describe the principles of research and scholarly inquiry

b. Describe the principles of research ethics especially in application to infants and pregnancies
c. Complete a scholarly research project related to neonatal hemodynamics that can be and is not limited to Clinical Research, Epidemiology, Education or Quality Improvement. This project must be relevant to Neonatal-Perinatal Medicine and suitable for peer-reviewed publication or presentation at an academic meeting
   i. Present the scholarly project at a national, or international forum

Program Structure and content:

The Clinical Research Neonatal Hemodynamics program consists of 1 or 2 years of additional training in hemodynamics / echocardiography research targeted to the neonatal population with research methods, under the supervision of a primary faculty supervisor. The duration of the fellowship will depend on the predicted time frame of the research project and funding. The supervisor and the duration of the fellowship will be identified and agreed by all concerned, including the fellowship director, before the fellowship begins. A 1-year fellowship may be extended to a 2nd year if all parties agree (including McGill University postgraduate office and the sponsor, where applicable). Patient care responsibilities are designed to maintain clinical competence in Neonatology and to enhance knowledge and experience in neonatal diseases targeted by the fellow's research.

Only PhD or MD researchers with faculty appointments at McGill University will be permitted to supervise research fellows. The fellowship director and fellowship committee members must approve research proposals.

Block	1	2-3	4	5 - 6	7 – 10	11	12 - 13
Exposure	Orientation block	ECHO lab	4 weeks clinical JGH/MUHC*	Research	Research	Elective*	Research
Research Phase	Research: PHASE A			Research: PHASE A	Research: PHASE B		Research: PHASE C
Call /shift expectations	7 shifts in NICU/block (including 1 week-end)		No calls	7 shifts in NICU/block (including 1 week-end)			

Training:
A. **Longitudinal Research Experience**: Supervised echocardiography laboratory and clinical/epidemiologic research for 11 (for a 13 blocks program) but up to 22 blocks for a 26 blocks program. In year 1, phase A to C. If second year, extension of Phase B and Phase C.
   a. Phase A) Expectations: orientation to the program, orientation to echocardiography machine, Endnote course at the MUHC library, "Research of literature course" (OVID and Pubmed) at the MUHC library, introduction to research, preparation of the literature review, training for the research ethics board (REB) submission and requirements, concept for the development of the research protocol, REB submission if necessary (Nagano, research modules for MUHC-RI, RedCAP training), mandatory

readings and learning provided in Appendix B, log book creation, Neonatal Resuscitation Program training if not accomplished, certification on the defibrillator and its use in the NICU and meeting with the librarian regarding research project, orientation to the units (JGH, MUHC).

  i. In phase A: Learning the views of echocardiography (mandatory readings, 1 on 1 training) and learning the standardized measures and their meanings, learning how to use a software for data extraction. Orientation of ongoing research projects in the Research lab. Scanning of participants (which my happen on both sites: JGH/MUHC).

  ii. In phase A: Please refer to "Acquisition of Skills"

  b. Phase B) Data collection, scanning of participants
  c. Phase C) Data extraction, data consolidation, data analysis, conclusions and presentation. Preparation of poster, abstract, manuscript. Ongoing scanning for the participants of research projects.

B. **Clinical:** 1 to 2 blocks of NICU service per year (2-4 weeks x 2 at MUHC, based on funding source and length of fellowship)

C. **Elective:** Highly recommended Hemodynamics rotation at the CHU Sainte-Justine, otherwise: cardiac anesthesia, cardiology, cardiac critical care, neonatal follow-up (emphasis on cardiac patients).

D. **Teaching**:
  a. Mandatory: 4 Friday afternoon teaching sessions given to NPM residents related to cardiovascular anomalies of the newborn (arrhythmias, pulmonary hypertension, patent ductus arteriosus, congenital heart defect)
  b. Mandatory: 1 presentation per year at Neonatal Rounds
  c. Mandatory: 2 presentations at Journal Club with article related to neonatal hemodynamics
  d. Mandatory: 3 case presentations per year at Quebec-TnECHO meetings
  e. Mandatory: 2 mock codes in the NICU related to a Neonatal Hemodynamics Case
  f. Optional: 2 Tuesday afternoon teaching sessions given to pediatric residents,
  g. Optional: Help teach 1 class in CCHCSP,

Acquisition of technical skills (Part of Phase A)
  a) Echocardiography Laboratory rotation: During their first year, the fellow will spend two months in the Echocardiography Laboratory. During that time, they will work with both sonographers and echocardiography attendings to learn to acquire, as well as interpret standard echocardiographic views.
  b) Simulation Cases (optional but highly recommended): the trainee will be exposed to the simulator owned by Dr Anie Lapointe and Dr Andréanne Villeneuve (CHU Sainte-Justine), shared for the training of fellows at McGill University.
  c) Ongoing scanning: The trainee will be involved in the scanning of participants in research projects throughout the training period. This will continue in Phase B and Phase C.

Evaluation:
1-Senior Research ITER to be completed after every research block by the primary supervisor
2-Junior Attending ITER to be completed after every NICU rotation (2 per year) by the supervising Neonatologist.
3-Echocardiography rotation ITER to be completed by cardiologist supervising the rotation (Dr Tiscar Cavalle is responsible for the rotation).
Supervising attendings may complete O-scores
The competence committee will review and complete summative evaluations every 6 months.

Lectures and readings:
Lectures: The trainee will be exposed to lectures, case presentations and mandatory readings throughout the curriculum. Lectures will occur every other weeks (Thursday afternoon) on material that may be presented by the trainee, by the program director or by an invited speaker. During block 1, there will be a mandatory presence for an introductory echocardiography course (by Dr. G. Altit). The minimum content that will be covered by the lectures and mandatory readings include:

Basic echocardiography (5, 6):
- Echocardiography: principles, safety, aliasing, Doppler, M-mode
- Echocardiography: Obtaining the standard views and assessment of gradients, Bernouilli equation and its limitations
- Assessment of shunts: VSD, PDA, ASD and what to understand from them?
- Heart function (part 1): the left side (7, 8)
- Heart function (part 2): the right side (9-11)

Heart, Physiology and Pharmacology (5, 6, 12, 13):
- Transitional physiology, fetal and immediate neonatal hemodynamics / adaptation
- Cardiovascular embryology
- Basic cardiac anatomy, nomenclature and clinical application
- Pharmacology of cardiovascular drugs: inotropes
- Pharmacology of cardiovascular drugs: anti-pulmonary hypertension medications
- The case of inhaled Nitric Oxide

Neonatal diseases and their hemodynamics (5, 6)
- The extreme preterm: when the focus is perfusion and not blood pressure
- Persistent pulmonary hypertension of the newborn: clinical vignettes, diagnosis and management
- Controversies about the patent ductus arteriosus: to treat or not to treat? (14-16)
- Current understanding about hemodynamic impact of a large persistent ductus (17-19)
- Septic shock and NEC in the newborn: pathophysiology, diagnosis, hemodynamic impact
- Septic shock and NEC in the newborn: management and outcome
- HIE: hemodynamic management for brain safety

- Congenital Diaphragmatic hernia: the hemodynamic golden hour
- Management and controversies about congenital diaphragmatic hernia: management of pulmonary pressures, heart function, fluid status and timing of surgery
- BPD and pulmonary hypertension: epidemiology, pathophysiology, screening and diagnosis
- BPD and pulmonary hypertension: controversy about management and invasive testing
- The extremes: severe IUGR and infant of mother with preeclampsia
- The extremes: the LGA and infant of diabetic mother

Cardiac anomalies (5, 6)
- Coarcatation of the aorta and hypoplastic arch
- Tricuspid atresia, Ebstein's anomaly, pulmonary atresia intact septum
- L-TGA and D-TGA
- Anomalies of the mitral valve, Hypoplastic Left Heart Syndrome and variants, Shone's complex
- Pulmonary veins, left sided obstruction and post-capillary hypertension (MS, MR)
- TOF and DORV
- Coronary anomalies – fistula, sinusoids, ALCAPA and abnormal insertion
- Genetic syndromes and their cardiac involvement
- Endocarditis and inflammatory disease of the myocardium (infants of lupique mothers)
- Pericardial effusion and how to recognize tamponade in the newborn

Other advanced diagnostic and therapeutic measures(5, 6)
- Advanced echocardiography: how to understand a report and a journal article about TDI, 3D imaging, strain and speckle tracking echocardiography
- NIRS and its applications: current knowledge of literature
- Biomarkers: the right ventricle, the left ventricle and the pulmonary vasculature
- MRI, VQ scan and CT: how they complement your assessment
- Basic understanding of ECMO: cannulation, circuit, VV, VA
- Basic understanding of cardiac transplant and ventricular assist device
- Basic understanding of cardiac catheterization and how to interpret a diagnostic study

Research and Epidemiology:
- Preparation of a research questions
- Critically appraise the literature: observational studies, cohort studies, randomized control trials, meta-analysis
- Understand basic statistical tests and epidemiological strategies to analyze data
- Study designs
- How to prepare a poster, manuscript and abstract
- CV preparation

Mandatory readings will be provided to the trainee at the beginning of the year and complemented throughout the training. Please refer to Appendix B.

Trainee should attend at least one conference among these during the year(s) of training: NeoHeart, Pediatric Academic Societies, UCSF Neonatal Pulmonary Vascular Disease Conference, NeoPOCUS workshop, American Academy of Pediatrics, Canadian Pediatric Society, American Society of Echocardiography, American Thoracic Society meeting.

Mandatory Local Conference attendance:
1-Neonatal Rounds every Friday afternoon
2-Journal club every other Tuesday morning
3-Neonatal Cross-Canada Rounds (4 times a year)
4- Canadian Child Health Clinician Scientist Program (CCHCSP) training at the MUHC

Fellow Duties, responsibilities and resources:
A. Call: 7 in-house shifts (night class and/or week end shifts) per block (alternating between JGH and MUHC sites), as decided by the program director based on source of funding.
B. Resident Supervision: The fellow will supervise residents and students during clinical duties and will provide mid-rotation and end of rotation feedback.
C. Academic Activities: Fellow should present his/her work at a national or international conference. The fellow is expected to present his/her work at the Neonatal Rounds - MUHC.
D. Support staff: Administrative tasks will be managed by the program coordinator.
E. Will need to keep track of echocardiography done on participants / patients and on simulator. Logbook will be available for the trainee. Data from the log-book will be reviewed 3 times per year with the trainee, but will not be accounted for in an evaluation.

Professional:
A. Model and mentor principles of medical professionalism
B. Model and mentor principles of commitment to patients, profession, and society through ethical practice
C. Model and mentor principles of commitment to patients, the profession, and society through participation in profession-led regulation

Academic Facilities:
Jewish General Hospital:
Neonatal Intensive Care Unit, office space
Montreal University Hospital Center:
Neonatal Intensive Care Unit, office space
CHU Sainte-Justine (elective site):
Neonatal Intensive Care Unit, office space
Libraries and information Technology:

Electronic access to McGill Life Sciences Library from computers in dedicated resident/fellow rooms at each site; hospital libraries accessible at all training sites
Research Institute
Computer lab, biostatistics support and clinical research infrastructure

Selection of Candidates:
Interest in training may be expressed by contacting the Program Director (Dr. Gabriel Altit – Gabriel.altit@mail.mcgill.ca) or the Fellowship Coordinator (Tamara Slovick - tamara.slovick@muhc.mcgill.ca). We will seek candidates with a special interest in neonatal hemodynamics clinical research. Selection will be done by personal statement (maximum 1 page), CV, interview and two reference letters. Successful and non-successful applicants will be informed within two weeks of the interview.

Teaching Faculty and Research Interests are available at:
https://www.mcgill.ca/peds/education-training/pgme/programs/neonatology/fellowship
https://www.mcgill.ca/pgme/admissions/prospective-fellows
www.neocardiolab.com

Other Resources:
http://echocardiographyskills.com/
http://www.neonatalechoskills.com/ - http://neonatalechoskills.com/course.html
http://tnecho.com/
https://winnipegneonatal.wordpress.com/category/hemodynamics/
http://ipokrates.info/?event=cardiac-intensive-care-of-newborn-and-children
http://www.bevtsai.com/echo%20course.html
http://www.rbht.nhs.uk/healthprofessionals/clinical-departments/paediatrics/morphology/echocardiography-in-chd/
http://www.echocardiography-course.com/
http://www.neonatalcardiology.co.uk/
http://www.ardms.org/get-certified/RDCS/Pages/pediatric-echocardiography.aspx
https://ecgwaves.com/course/clinical-echocardiography/
https://www.echopedia.org/
http://sites.austincc.edu/sonography-resources/

APPENDIX A: Echocardiography protocols:

A) First Study (Complete protocol):
During echocardiography, always note: weight, age of patient, systemic blood pressure at the time of echocardiography. Record echocardiography with ECG recording. Scale of Nyquist velocity needs to be adapted in consideration of expected blood velocities. As such, a lower scale (40 to 60 cm/s) needs to be used in the context of: screening for ventricular septal defect in the immediate neonatal life (due to higher pulmonary pressures), coronary flow, venous flow, atrial septal defect shunting evaluation.

In all the views, appreciate the subjective contraction of each portion of the left and right ventricles, looking at segmental decrease in contraction. For Tissue Doppler Imaging, acquire images at high frame rates (150 fps) and record multiples beats (5 per loop).

Views and comprehensive first study:
1) **Parasternal long axis view (PLA):** The septum is nearly horizontal, and deviates less than 30° from the horizontal plane. The aortic valve and mitral valve are each displayed, as is the proximal aorta. The ventricular septum should be seen 2/3 to the apex.

   a. 2D image at the level of mitral and aortic valve, aortic root and cusps. Aortic valve, aortic root and ascending aorta measurements – 2D anatomy, Color Doppler on mitral valve, aortic valve
   b. Sweep posterior at the level of RV inflow (tricuspid valve) – 2D anatomy and Color Doppler on tricuspid valve
   c. Sweep anterior at the level of RV outflow tract (pulmonary valve and pulmonary artery) – 2D anatomy - Color Doppler on pulmonary valve, as well as pulmonary artery – PW Doppler at pulmonary valve leaflets attachment and in MPA
   d. Continuous wave (CW) Doppler interrogation of valvar insufficiency at tricuspid and pulmonary level if present and if aligned appropriately. Measure peak TR gradient, early diastolic and end diastolic PI gradient.
   e. Sweep from posterior to anterior to establish atrio-ventricular and ventriculo-arterial connections
   f. M-mode of left and right ventricle at the level of tip of mitral valve with line of interrogation perpendicular to interventricular septum for measurement of shortening fraction (SF) and measurements of LV / RV / Septum / Posterior wall thickness (only valid in normal biventricular anatomy), measurement of R-R interval.
   g. M-mode at the closure of aortic valve and with line of interrogation perpendicular to aorta for: Left atrial on aorta ratio (detection of signs of LV overload, or small aortic valve). Evaluation of LV ejection time from opening to closure of aortic valve.
   h. Color Doppler of all interventricular septum for detection of VSDs (visualize up to the apex). Sweep in every plane from posterior (tricuspid valve level) to anterior (pulmonary valve level) – lower Nyquist in early neonatal period due to low blood velocity in the context of higher pulmonary pressures in the first few days of life. With decrease pulmonary pressures in time, higher possible Nyquist. If VSD detected and aligned with jet: CW Doppler interrogation through the VSD for gradient velocity
   i. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).
2. **Parasternal short axis view (PSA)**
   a. 2D anatomy sweep from the aortic level to the apex

b. 2D anatomy image of the aortic valve: confirmation of the tricuspid opening of the aortic valve – Fusion of leaflets may not be obvious and the valve need to be seen opening in a tri-leaflet manner

c. 2D anatomy and zoom on left coronary artery (LCA) opening and right coronary artery opening. Delimitation of coronary system anatomy including division with circumflex coronary from LCA. Color Doppler of LCA and RCA with demonstration of flow during diastole with low Nyquist velocity. Measurements of coronary if dilation.

d. 2D capture of the RV-LV interaction at the mid-papillary level. Evaluation of septal curvature at the end of systole. Septal curvature was described and validated for the end of systole. Clinically, septal curvature is often appreciated throughout the cardiac cycle: diastole and systole. Measurement of eccentricity index.

e. Confirmation of 2 LV papillary muscles (anterolateral and posteromedial).

f. M-mode can be taken at mid-papillary level for quantification of SF (if not done in the PLA)

g. Color Doppler of the septum from aortic valve area to the apex (lower Nyquist in early neonatal period, highest Nyquist possible for visualization of flow) to rule out VSD. Consider CW Doppler across detected VSD if aligned with jet.

h. 2D and Color Doppler at the tricuspid valve and CW Doppler interrogation if regurgitation present for estimation of RV pressure

i. 2D and Color Doppler at the pulmonary valve and branched pulmonary arteries and CW Doppler interrogation if insufficiency present.
   i. Sometimes, LPA and RPA bifurcation requires a different incidence - upper on the chest in PSA. Measure in 2D the left and right pulmonary arteries (LPA and RPA) at their maximum diameter. Look at flow with color Doppler. Interrogation of flow by PW and CW Doppler in MPA, LPA and RPA.

j. This is not the ideal view to look at the atrial septum, although it can be appreciated partly in this view. At the left atrial level, color Doppler with low Nyquist velocity could demonstrate pulmonary veins. However, the best views for pulmonary veins remain often in the suprasternal area. If pulmonary veins are visualized, confirmation of their introduction at the left atrium needs to be done with PW Doppler at insertion for each pulmonary vein.

k. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).

3. **Apical view: 4 chambers, 5 chambers, LV 2 chambers**
   a. 2D anatomy sweep from posterior to anterior (posterior wall to pulmonary arteries) – appreciation of caliber of the coronary sinus (if dilated, look for bilateral SVC).
   b. 2D evaluation of mitral and tricuspid valve with measurements (often requires two different views for their maximal size)
   c. Color Doppler of mitral valve
   d. Color Doppler of tricuspid valve

e. CW Doppler interrogation of tricuspid regurgitation with appropriate alignment

f. Pulsed wave (PW) Doppler at inlet of LV and RV (transmitral and transtricuspid flow)
    i. E and A waves of LV and RV inlet (tip of Mitral and Tricuspid valve)
    ii. Use of CW Doppler if acceleration (obstruction or regurgitation) in order to calculate mean and peak velocities

g. Color Doppler of septum from anterior to posterior for perimembranous and muscular VSDs (same concept applies for Nyquist velocity in the context of similar LV and RV afterload in the early life). Visualize the apex for apical VSD.

h. Left sided pulmonary veins and right superior pulmonary vein can sometimes be seen entering the left atrium in the apical 4 chamber view by color Doppler.

i. 5 Chamber view with anatomy demonstrating LV outflow tract (LVOT) with aortic valve and ascending aorta.
    i. Color Doppler of flow through LVOT. PW Doppler at subaortic outlet for signs of subaortic obstruction, CW Doppler in Ascending Aorta past the valve for signs of acceleration of flow. PW in ascending aorta past the aortic valve for VTI calculation.
    ii. Sweep anteriorly and 2D visualization of RV outflow tract (RVOT)
    iii. Color Doppler of RVOT with PW Doppler at subpulmonic area and CW/PW Doppler past the pulmonary valve in MPA.
    iv. Evaluation for pulmonary insufficiency and interrogation by CW Doppler.
    v. Sweep of septum in 5 chamber view from anterior to posterior for VSD detection. If VSD detected, CW Doppler gradient interrogation for gradient velocity

j. In evaluation of function:
    i. Ejection fraction by biplane Simpson's method using 4 chambers view and 2 chambers LV view.
    ii. Tissue Doppler imaging (TDI) with interrogation at MV annulus at LV free wall, MV annulus at septal wall and tricuspid annulus at RV free wall; calculation of e', a', E/e', MPI (myocardial performance index or Tei index) of LV and RV, TAPSE (tricuspid annular plain systolic excursion).

k. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).
    i. In the context of pericardial fluid, inflow of mitral and tricuspid valve need to be interrogated by PW Doppler in a compressed time matter for signs of tamponade (evaluate for fluctuation in time of the velocity of inflow). If suspicion of tamponade, PW Doppler interrogation of SVC and IVC needs to be done in the subcostal view for retrograde flow assessment.

4. **Subcostal view: long axis and short axis (SCL and SCS)**

a. SCL view – coronal cut:
   i. SCL for situs evaluation (inferior vena cava (IVC) to the right and posterior compared to the descending aorta). Sweep to ensure connection of IVC to right atrium with cross-section of spine.
   ii. Visualization of a line in the IVC (in cross-section) at connection with the right atrium, or an umbilical arterial line in the descending aorta in cross-section.
   iii. Atrial septal 2D evaluation
   iv. Atrial septum color Doppler evaluation and measurement (consider PW Doppler interrogation if acceleration of shunt flow across atrial septal defect or patent foramen ovale; consider M-Mode with color Doppler to evaluate shunting direction of inter-atrial shunt)
   v. 2D scanning anatomy of SCL axis without color Doppler (establishing atrio-ventricular and ventriculo-arterial connections)
   vi. 2D scanning with color of SCL axis from posterior to anterior
   vii. 2D scanning of interventricular septum with color Doppler for detection of VSD with special interest at apex for apical VSD that can be missed easily
   viii. Evaluation of RV and RVOT in 2D motion for qualitative function looking at each segment from RV (inlet, midcavity, apex and RVOT) segmental contraction, especially in the context of pulmonary hypertension (some patients might have segmental wall dysfunction).
   ix. Evaluation by color Doppler of flow in LVOT to Aorta and in RVOT to pulmonary artery with no acceleration. Evaluation for pulmonary insufficiency and interrogation by CW Doppler.
   x. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).
b. SCS view – sagital cut:
   i. Evaluation of IVC connection to right atrium, visualization of line position
   ii. Color Doppler in IVC at RA junction with low Nyquist velocity
   iii. Color Doppler of subhepatic veins with low Nyquist and PW Doppler of hepatic veins – evaluation of retrograde flow in the subhepatic veins as a sign of abnormal RV diastolic function
   iv. 2D visualization of descending aorta (DesAo)
   v. Color Doppler of DesAo with PW Doppler for evaluation of diastolic extension of flow (ex: such as in coarctation) or retrograde DesAo flow (steal effect from a significant patent ductus, steal from significant atrial insufficiency, aorto-ventricular tunnel, pulmonary to aortic window, etc.). Note that the Doppler sampling is done at diaphragmatic level with minimal angle of insonation.
   vi. Some have advocated for evaluation of celiac flow by color Doppler in this view and with PW Doppler interrogation (peak, mean, end diastolic velocity) as a marker of intestinal steal during evaluation of PDA significance.

      vii. 2D sweep of anatomy in SCS view from IVC/SVC to apex (establishing atrio-ventricular and ventriculo-arterial connections); although this is not the typical view to appreciate LV-RV interaction in terms of septal curvature, some might appreciate indirect signs of RV overload with bowing of septum to LV side. Validated evaluation of septal curvature was described only in the PSA view.

      viii. Visualization of SVC to RA with 2D clip and color Doppler in bicaval view (showing IVC and right SVC junctions to right atrium)

      ix. Color Doppler at junction of SVC and RA to rule out ASD of the sinus venosus defect type. Right superior pulmonary vein can be often seen in this area and a PW Doppler should be sampled.

      x. Atrial septal scanning in SCS view with evaluation of rim size of ASD or PFO in 2D; evaluation of color Doppler with shunt direction through inter-atrial communication if present (low Nyquist velocity)

      xi. Color Doppler of mitral valve, septum for VSD, LVOT and RVOT

      xii. 2D evaluation of RVOT for subpulmonary RVOT narrowing and malalignment of muscular outlet septum

      xiii. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).

5. Modified Parasternal Short axis view (mPSA) or PDA view
    a. View of PDA in 2D with connection from pulmonary to aortic side; measurements of PDA (prioritize 2D anatomy measurements of the narrowest point)
    b. Color Doppler of PDA: shunt direction
    c. CW Doppler of PDA: quantification of shunt gradient velocities
    d. M-Mode with Color Doppler for shunt directionality

6. Suprasternal view short and long axis (SSS and SSL)
    a. SSS view:
      i. Visualization of 2D anatomy with confirmation of left sided-arch and appropriate vessel branching to the right
      ii. Visualization of RPA course and Color Doppler for acceleration
      iii. Color Doppler of SVC to right atrium and innominate bridge
      iv. Evaluation for possibility of left-sided SVC (especially in the context of a dilated coronary sinus) – rule out coarctation if presence of left SVC to coronary sinus.
      v. Very anterior sweep for pulmonary veins evaluation ("crab view"): PW Doppler of the 4 pulmonary veins at their connection with the left atrium to rule out partial or total anomalous pulmonary venous return
    b. SSL view
      i. Visualization of 2D anatomy and measurements of aorta at Ascending Aorta, Transverse Aorta, Isthmus and Descending Aorta. Look for a posterior shelf at the descending aorta.
      ii. Color Doppler for acceleration of flow and rule out coarctation; CW in the descending Aorta

1. Note that the PDA may be seen in many views, including this one
   iii. PW Doppler in the distal descending Aorta, past the ductus for distal coarctation and flow pattern
   iv. Second sweep in the neck in SSL for confirmation of right branching and left sided arch; rule out double arch

Middle cerebral artery:
- Some groups have used the PW Doppler profile and calculation of resistive index and pulsatility index, as well as pattern of diastolic flow in the middle cerebral artery as an indicator of PDA significance.

Special note on LV and RV cardiac output and SVC flow measurements by echocardiography:
It has been advocated by some studies and some group publishing on TNE to evaluate left and right cardiac output, as well as, SVC flow using echocardiography. When done systematically by an experienced sonographer, cardiac output estimation may be of interest. However, due to the extrapolation of a valvular surface area from a 2D measurement subject to inter-observer and intra-observer variability, this measurement can often be erroneous. Currently, the principle relies on measurement of the diameter of the respective outflow tract, with use of the velocity time integral (VTI = area under the curve during one systolic heartbeat of the PW Doppler tracing) of the respective outflow tract). The LVOT is measured in PLA and the PW Doppler envelope is measured in the apical 5 chamber view. The RVOT is measured in the PSA with the PW Doppler envelope interrogated in the same view. The cross-sectional area (CSA) of the outflow tracts is calculated with Pi/4 x Diameter^2. The cardiac output (CO) is extrapolated with VTI x CSA x Heart rate and is indexed by dividing by weight of the patient. CO is expressed in mL/Kg/min. The left ventricular cardiac output (LVO) is expressed in ml/kg/min. Normal values range from 170 to 450 ml/kg/min in neonates for LVO. Normal values range from 230 to 750 ml/kg/min in neonates for RV cardiac output.

The SVC flow is calculated with similar measurements. SVC measurements fluctuate with breathing. SVC is visualized in subcostal view at the bicaval view. The PW Doppler is measured at the junction of the SVC and the right atrium. The average velocity is then calculated using the VTI of the curve. The 2D measurement of SVC is from the suprasternal short axis or high parasternal long axis view. Three to five 2D measurements should be done. SVC Flow is calculated with VTI x (Pi/4 x mean SVC diameter^2) x Heart rate / Body weight. A value below 40 ml/kg/min was associated with an increased risk of intra-ventricular haemorrhage and worst developmental outcomes in preterm infants.

B) PDA Protocol:

During echocardiography, always note: weight, age of patient, systemic blood pressure at the time of echocardiography. Record echocardiography with ECG recording. Scale of Nyquist velocity needs to be adapted in consideration of expected blood velocities.

In all the views, appreciate the subjective contraction of each portion of the left and right ventricles, looking at segmental decrease in contraction. For Tissue Doppler Imaging, acquire images at high frame rates (150 fps) and record multiples beats (5 per loop).

Specific markers of PDA significance:
- Size of PDA (by color and 2D, at its narrowest point)
- Color flow in PDA
- CW Doppler of PDA in Ductal view and gradient assessment
- LA/Ao ratio by M-mode (Normal if less than 1.4); signs of left sided volume overload (large left atrium, large left ventricle leading to mitral regurgitation and/or aortic insufficiency)
- LA/LPA ratio (Normal if less than 1)
- E/A Ratio of mitral valve inflow (more than 1.0)
- Retrograde flow in abdominal aorta during diastole (PW of Descending Aorta)
- Retrograde or absent flow in celiac/SMA
- Absent flow in the SMA (or resistive index more than 0.8 consistent with hsPDA)
- LV Output : RV Output ratio

Importance during assessment of PDA for closure or post-closure:
- Ensure no coarctation / RVOT or LVOT obstruction pre-closure
- Ensure no residual PDA, no obstruction in aorta or pulmonary artery post-ligation
- Assessment of function post-ligation is essential

Views for PDA protocol: *This protocol must be applied after first study done by cardiology and after ruling out the possibility of a ductal-dependent cardiac defect. One must be cautious in the context of a closed ductus to ensure that there is no underlying coarctation. The PDA protocol is to follow premature newborns when there is suspicion of a hemodynamically significant ductus, or as part of a treatment with NSAIDs or surrounding ligation (pre and post-OR).*

a) **Parasternal long axis view (PLA):** The septum is nearly horizontal, and deviates less than 30° from the horizontal plane. The aortic valve and mitral valve are each displayed, as is the proximal aorta. The ventricular septum should be seen 2/3 to the apex.
    a. 2D image at the level of mitral and aortic valve, aortic root and cusps. – 2D anatomy, Color Doppler on mitral valve, aortic valve
    b. Sweep posterior at the level of RV inflow (tricuspid valve) – 2D anatomy and Color Doppler on tricuspid valve
    c. Sweep anterior at the level of RV outflow tract (pulmonary valve and pulmonary artery) – 2D anatomy - Color Doppler on pulmonary valve, as well as pulmonary artery – PW Doppler at pulmonary valve leaflets attachment and in MPA. PDA might be viewed by color in this incidence.
    d. Continuous wave (CW) Doppler interrogation of valvar insufficiency at tricuspid and pulmonary level if present and if aligned appropriately. Measure peak TR gradient, early diastolic and end diastolic PI gradient.

e. M-mode of left and right ventricle at the level of tip of mitral valve with line of interrogation perpendicular to interventricular septum for measurement of shortening fraction (SF) and measurements of LV / RV / Septum / Posterior wall thickness (only valid in normal biventricular anatomy), measurement of R-R interval.

f. M-mode at the closure of aortic valve and with line of interrogation perpendicular to aorta for: Left atrial on aorta ratio (detection of signs of LV overload, or small aortic valve). Evaluation of LV ejection time from opening to closure of aortic valve.

g. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).

7. **Parasternal short axis view (PSA)**
   a. 2D anatomy sweep from the aortic level to the apex
   b. 2D capture of the RV-LV interaction at the mid-papillary level. Evaluation of septal curvature at the end of systole. Clinically, septal curvature is often appreciated throughout the cardiac cycle: diastole and systole.
   c. M-mode can be taken at mid-papillary level for quantification of SF (if not done in the PLA)
   d. Color Doppler of the septum from aortic valve area to the apex
   e. 2D and Color Doppler at the tricuspid valve and CW Doppler interrogation if regurgitation present for estimation of RV pressure
   f. 2D and Color Doppler at the pulmonary valve and branched pulmonary arteries and CW Doppler interrogation if insufficiency present. PDA might be viewed by color in this incidence. 2D measurement of RPA and LPA for ratio PDA to LPA. Color Doppler and CW/PW of both RPA and LPA (post-ligation, need to rule out obstruction of a pulmonary artery).
   g. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).

8. **Modified Parasternal Short axis view (mPSA) or PDA view**
   a. View of PDA in 2D with connection from pulmonary to aortic side; measurements of PDA (prioritize 2D anatomy measurements of the narrowest point)
   b. Color Doppler of PDA: shunt direction
   c. CW Doppler of PDA: quantification of shunt gradient velocities
   d. M-Mode with Color Doppler for shunt directionality

9. **Apical view: 4 chambers, 5 chambers, LV 2 chambers**
   a. 2D anatomy sweep from posterior to anterior (posterior wall to pulmonary arteries)
   b. 2D evaluation of mitral and tricuspid valve
   c. Color Doppler of mitral valve
   d. Color Doppler of tricuspid valve
   e. CW Doppler interrogation of tricuspid regurgitation with appropriate alignment
   f. Pulsed wave (PW) Doppler at inlet of LV and RV (transmitral and transtricuspid flow)

      i. E and A waves of LV and RV inlet (tip of Mitral and Tricuspid valve)
- g. Color Doppler of septum from anterior to posterior
- h. 5 Chamber view with anatomy demonstrating LV outflow tract (LVOT) with aortic valve and ascending aorta.
  - i. Color Doppler of flow through LVOT. PW in ascending aorta past the aortic valve for VTI calculation.
  - ii. Sweep anteriorly and 2D visualization of RV outflow tract (RVOT). Color Doppler of RVOT with PW Doppler past the pulmonary valve in MPA.
- i. Ejection fraction by biplane Simpson's method using 4 chambers view and 2 chambers LV view.
- j. Tissue Doppler imaging (TDI) with interrogation at MV annulus at LV free wall, calculation of e', a', E/e', MPI (myocardial performance index or Tei index) of LV
- k. TAPSE (tricuspid annular plain systolic excursion).
- l. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).

10. Subcostal view: long axis and short axis (SCL and SCS)
- a. SCL view – coronal cut:
  - i. Atrial septal 2D evaluation
  - ii. Atrial septum color Doppler evaluation
  - iii. 2D scanning anatomy of SCL axis with and without color Doppler.
- b. SCS view – sagital cut:
  - i. Evaluation of IVC connection to right atrium, visualization of line position
  - ii. 2D visualization of descending aorta (DesAo)
  - iii. Color Doppler of DesAo with PW Doppler for evaluation of diastolic extension of flow (ex: such as in coarctation) or retrograde DesAo flow (steal effect from a significant patent ductus, steal from significant atrial insufficiency, aorto-ventricular tunnel, pulmonary to aortic window, etc.). Note that the Doppler sampling is done at diaphragmatic level with minimal angle of insonation.
  - iv. Some have advocated for evaluation of celiac flow by color Doppler in this view and with PW Doppler interrogation (peak, mean, end diastolic velocity) as a marker of intestinal steal during evaluation of PDA significance.
  - v. 2D sweep of anatomy in SCS view from IVC/SVC to apex (establishing atrio-ventricular and ventriculo-arterial connections) + Color Doppler
  - vi. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).

11. Suprasternal view short and long axis (SSS and SSL)
- a. SSL view

      i. Visualization of 2D anatomy of Ascending Aorta, Transverse Aorta, Isthmus and Descending Aorta. Look for a posterior shelf at the descending aorta.

     ii. Color Doppler for acceleration of flow and rule out coarctation (in the context of a post-ligation study, need to rule out aortic obstruction); CW in the descending Aorta

         1. Note that the PDA may be seen in many views, including this one

    iii. PW Doppler in the distal descending Aorta, past the ductus for distal coarctation and flow pattern

12. RV and LV cardiac output calculations

Middle cerebral artery:
- Some groups have used the PW Doppler profile and calculation of resistive index and pulsatility index, as well as pattern of diastolic flow in the middle cerebral artery as an indicator of PDA significance.

C) <u>Heart function protocol</u>

During echocardiography, always note: weight, age of patient, systemic blood pressure at the time of echocardiography. Record echocardiography with ECG recording. Scale of Nyquist velocity needs to be adapted in consideration of expected blood velocities. In all the views, appreciate the subjective contraction of each portion of the left and right ventricles, looking at segmental decrease in contraction. For Tissue Doppler Imaging, acquire images at high frame rates (150 fps) and record multiples beats (5 per loop).

Goal of the heart function protocol
- Assessment of myocardial performance (RV and LV)
- Assessment of pulmonary pressures and shunts (at ductal and atrial level), such as in the context of shock or HIE
- Assessment of cardiac output (RV and LV)
- Rule out anatomic obstruction causing disturbed function
- Rule out cardiac tamponade

Views and comprehensive first study:
2) **Parasternal long axis view (PLA):** The septum is nearly horizontal, and deviates less than 30° from the horizontal plane. The aortic valve and mitral valve are each displayed, as is the proximal aorta. The ventricular septum should be seen 2/3 to the apex.

    j. 2D image at the level of mitral and aortic valve, aortic root and cusps. 2D anatomy, Color Doppler on mitral valve, aortic valve

    k. Sweep posterior at the level of RV inflow (tricuspid valve) – 2D anatomy and Color Doppler on tricuspid valve

    l. Sweep anterior at the level of RV outflow tract (pulmonary valve and pulmonary artery) – 2D anatomy - Color Doppler on pulmonary valve,   as

well as pulmonary artery – PW Doppler at pulmonary valve leaflets attachment and in MPA

    m. Continuous wave (CW) Doppler interrogation of valvar insufficiency at tricuspid and pulmonary level if present and if aligned appropriately. Measure peak TR gradient, early diastolic and end diastolic PI gradient.

    n. Sweep from posterior to anterior to establish atrio-ventricular and ventriculo-arterial connections

    o. M-mode of left and right ventricle at the level of tip of mitral valve with line of interrogation perpendicular to interventricular septum for measurement of shortening fraction (SF) and measurements of LV / RV / Septum / Posterior wall thickness (only valid in normal biventricular anatomy), measurement of R-R interval.

    p. M-mode at the closure of aortic valve and with line of interrogation perpendicular to aorta for: Left atrial on aorta ratio (detection of signs of LV overload, or small aortic valve). Evaluation of LV ejection time from opening to closure of aortic valve.

    q. Color Doppler of all interventricular septum

    r. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).

13. Parasternal short axis view (PSA)

    a. 2D anatomy sweep from the aortic level to the apex

    b. 2D anatomy image of the aortic valve

    c. 2D capture of the RV-LV interaction at the mid-papillary level. Evaluation of septal curvature at the end of systole. Septal curvature was described and validated for the end of systole. Clinically, septal curvature is often appreciated throughout the cardiac cycle: diastole and systole. Measurement of eccentricity index.

    d. M-mode can be taken at mid-papillary level for quantification of SF (if not done in the PLA)

    e. Color Doppler of the septum from aortic valve area to the apex

    f. 2D and Color Doppler at the tricuspid valve and CW Doppler interrogation if regurgitation present for estimation of RV pressure

    g. 2D and Color Doppler at the pulmonary valve and branched pulmonary arteries and CW Doppler interrogation if insufficiency present.

        i. Sometimes, LPA and RPA bifurcation requires a different incidence - upper on the chest in PSA. Look at flow with color Doppler. Interrogation of flow by PW and CW Doppler in MPA, LPA and RPA.

    h. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).

14. Apical view: 4 chambers, 5 chambers, LV 2 chambers

    a. 2D anatomy sweep from posterior to anterior (posterior wall to pulmonary arteries)

    b. 2D evaluation of mitral and tricuspid valve with measurements (often requires two different views for their maximal size)

    c. Color Doppler of mitral valve

d. Color Doppler of tricuspid valve
e. CW Doppler interrogation of tricuspid regurgitation with appropriate alignment
f. Pulsed wave (PW) Doppler at inlet of LV and RV (transmitral and transtricuspid flow)
   i. E and A waves of LV and RV inlet (tip of Mitral and Tricuspid valve)
   ii. Use of CW Doppler if acceleration (obstruction or regurgitation) in order to calculate mean and peak velocities
g. Color Doppler of septum from anterior to posterior
h. 5 Chamber view with anatomy demonstrating LV outflow tract (LVOT) with aortic valve and ascending aorta.
   i. Color Doppler of flow through LVOT. PW Doppler at subaortic outlet for signs of subaortic obstruction, CW Doppler in Ascending Aorta past the valve for signs of acceleration of flow. PW in ascending aorta past the aortic valve for VTI calculation.
   ii. Sweep anteriorly and 2D visualization of RV outflow tract (RVOT)
   iii. Color Doppler of RVOT with PW Doppler at subpulmonic area and CW/PW Doppler past the pulmonary valve in MPA.
   iv. Evaluation for pulmonary insufficiency and interrogation by CW Doppler.
i. In evaluation of function:
   i. Ejection fraction by biplane Simpson's method using 4 chambers view and 2 chambers LV view.
   ii. Tissue Doppler imaging (TDI) with interrogation at MV annulus at LV free wall, MV annulus at septal wall and tricuspid annulus at RV free wall; calculation of e', a', E/e', MPI (myocardial performance index or Tei index) of LV and RV
   iii. TAPSE (tricuspid annular plain systolic excursion).
j. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).
   i. In the context of pericardial fluid, inflow of mitral and tricuspid valve need to be interrogated by PW Doppler in a compressed time matter for signs of tamponade (evaluate for fluctuation in time of the velocity of inflow). If suspicion of tamponade, PW Doppler interrogation of SVC and IVC needs to be done in the subcostal view for retrograde flow assessment.

15. Subcostal view: long axis and short axis (SCL and SCS)
a. SCL view – coronal cut:
   i. 2D Sweep to ensure connection of IVC to right atrium with cross-section of spine.
   ii. Atrial septal 2D evaluation
   iii. Atrial septum color Doppler evaluation and measurement (consider PW Doppler interrogation if acceleration of shunt flow across atrial septal defect or patent foramen ovale; consider M-Mode with color Doppler to evaluate shunting direction of inter-atrial shunt)

       iv. 2D scanning with color of SCL axis from posterior to anterior
       v. Evaluation of RV and RVOT in 2D motion for qualitative function looking at each segment from RV (inlet, midcavity, apex and RVOT) segmental contraction, especially in the context of pulmonary hypertension (some patients might have segmental wall dysfunction).
       vi. Evaluation by color Doppler of flow in LVOT to Aorta and in RVOT to pulmonary artery with no acceleration. Evaluation for pulmonary insufficiency and interrogation by CW Doppler.
       vii. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).

b. SCS view – sagital cut:
       i. Color Doppler in IVC at RA junction with low Nyquist velocity
       ii. Color Doppler of subhepatic veins with low Nyquist and PW Doppler of hepatic veins – evaluation of retrograde flow in the subhepatic veins as a sign of abnormal RV diastolic function
       iii. 2D visualization of descending aorta (DesAo)
       iv. Color Doppler of DesAo with PW Doppler for evaluation of diastolic extension of flow. Note that the Doppler sampling is done at diaphragmatic level with minimal angle of insonation.
       v. 2D sweep of anatomy in SCS view from IVC/SVC to apex (establishing atrio-ventricular and ventriculo-arterial connections); although this is not the typical view to appreciate LV-RV interaction in terms of septal curvature, some might appreciate indirect signs of RV overload with bowing of septum to LV side. Validated evaluation of septal curvature was described only in the PSA view.
       vi. Visualization of SVC to RA with 2D clip and color Doppler in bicaval view (showing IVC and right SVC junctions to right atrium)
       vii. Atrial septal scanning in SCS view with evaluation of rim size of ASD or PFO in 2D; evaluation of color Doppler with shunt direction through inter-atrial communication if present (low Nyquist velocity)
       viii. Color Doppler of mitral valve, septum for VSD, LVOT and RVOT
       ix. 2D evaluation of RVOT
       x. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).

16. Modified Parasternal Short axis view (mPSA) or PDA view
a. View of PDA in 2D with connection from pulmonary to aortic side; measurements of PDA (prioritize 2D anatomy measurements of the narrowest point)
b. Color Doppler of PDA: shunt direction
c. CW Doppler of PDA: quantification of shunt gradient velocities
d. M-Mode with Color Doppler for shunt directionality

17. Suprasternal view short and long axis (SSS and SSL)
a. SSS view:
       i. Visualization of 2D anatomy
       ii. Color Doppler of SVC to right atrium and innominate bridge

iii. Very anterior sweep for pulmonary veins evaluation ("crab view"): PW Doppler of the 4 pulmonary veins at their connection with the left atrium to rule out partial or total anomalous pulmonary venous return

b. SSL view

i. Visualization of 2D anatomy of aorta at Ascending Aorta, Transverse Aorta, Isthmus and Descending Aorta. Look for a posterior shelf at the descending aorta.

ii. Color Doppler for acceleration of flow and rule out coarctation; CW in the descending Aorta

1. Note that the PDA may be seen in many views, including this one

LV and RVOT assessment

D) Pulmonary Hypertension protocol:

During echocardiography, always note: weight, age of patient, systemic blood pressure at the time of echocardiography. Record echocardiography with ECG recording. Scale of Nyquist velocity needs to be adapted in consideration of expected blood velocities. In all the views, appreciate the subjective contraction of each portion of the left and right ventricles, looking at segmental decrease in contraction. For Tissue Doppler Imaging, acquire images at high frame rates (150 fps) and record multiples beats (5 per loop).

Goals of PH protocol:
- Assessment of pulmonary pressures and right ventricular function
- Prior to the start of medications affecting the pulmonary vascular bed (e.g. iNO, milrinone, sildenafil, bosentan, prostacyclin analogs), such as in the context of PPHN
  o To assess response to therapy (e.g. iNO)
- For screening of PH in patients with bronchopulmonary dysplasia (not initial study)
- For follow-up evaluations of patients with congenital diaphragmatic hernia

Views to acquire on a PH protocol:
3) **Parasternal long axis view (PLA):** The septum is nearly horizontal, and deviates less than 30° from the horizontal plane. The aortic valve and mitral valve are each displayed, as is the proximal aorta. The ventricular septum should be seen 2/3 to the apex.

    s. 2D image at the level of mitral and aortic valve, aortic root and cusps. Aortic valve, aortic root and ascending aorta – 2D anatomy, Color Doppler on mitral valve, aortic valve

    t. Sweep posterior at the level of RV inflow (tricuspid valve) – 2D anatomy and Color Doppler on tricuspid valve

    u. Sweep anterior at the level of RV outflow tract (pulmonary valve and pulmonary artery) – 2D anatomy - Color Doppler on pulmonary valve, as

well as pulmonary artery – PW Doppler at pulmonary valve leaflets attachment and in MPA

    v. Continuous wave (CW) Doppler interrogation of valvar insufficiency at tricuspid and pulmonary level if present and if aligned appropriately. Measure peak TR gradient, early diastolic and end diastolic PI gradient.

    w. Sweep from posterior to anterior; subjective assessment of RV function

    x. M-mode of left and right ventricle at the level of tip of mitral valve with line of interrogation perpendicular to interventricular septum for measurement of shortening fraction (SF) and measurements of LV / RV / Septum / Posterior wall thickness (only valid in normal biventricular anatomy), measurement of R-R interval.

    y. M-mode at the closure of aortic valve and with line of interrogation perpendicular to aorta for: Left atrial on aorta ratio (detection of signs of LV overload, or small aortic valve). Evaluation of LV ejection time from opening to closure of aortic valve.

    z. Color Doppler of all interventricular septum for detection of VSDs (visualize up to the apex). Sweep in every plane from posterior (tricuspid valve level) to anterior (pulmonary valve level) – lower Nyquist in early neonatal period due to low blood velocity in the context of higher pulmonary pressures in the first few days of life. With decrease pulmonary pressures in time, higher possible Nyquist. If VSD detected and aligned with jet: CW Doppler interrogation through the VSD for gradient velocity

    aa. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).

18. Parasternal short axis view (PSA)

    a. 2D anatomy sweep from the aortic level to the apex

    b. 2D capture of the RV-LV interaction at the mid-papillary level. Evaluation of septal curvature at the end of systole. Septal curvature was described and validated for the end of systole. Clinically, septal curvature is often appreciated throughout the cardiac cycle: diastole and systole. Measurement of eccentricity index.

    c. M-mode can be taken at mid-papillary level for quantification of SF (if not done in the PLA)

    d. Color Doppler of the septum from aortic valve area to the apex. Consider CW Doppler across detected VSD if aligned with jet.

    e. 2D and Color Doppler at the tricuspid valve and CW Doppler interrogation if regurgitation present for estimation of RV pressure

    f. 2D and Color Doppler at the pulmonary valve and branched pulmonary arteries and CW Doppler interrogation if insufficiency present.

        i. Sometimes, LPA and RPA bifurcation requires a different incidence - upper on the chest in PSA. Measure in 2D the left and right pulmonary arteries (LPA and RPA) at their maximum diameter. Look at flow with color Doppler. Interrogation of flow by PW and CW Doppler in MPA, LPA and RPA.

    g. This is not the ideal view to look at the atrial septum, although it can be appreciated partly in this view. At the left atrial level, color Doppler   with

low Nyquist velocity could demonstrate pulmonary veins. However, the best views for pulmonary veins remain often in the suprasternal area. If pulmonary veins are visualized, confirmation of their introduction at the left atrium needs to be done with PW Doppler at insertion for each pulmonary vein.

h. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).

19. Apical view: 4 chambers, 5 chambers, LV 2 chambers

a. 2D anatomy sweep from posterior to anterior (posterior wall to pulmonary arteries)

b. 2D evaluation of mitral and tricuspid valve

c. Color Doppler of mitral valve

d. Color Doppler of tricuspid valve

e. CW Doppler interrogation of tricuspid regurgitation with appropriate alignment

f. Pulsed wave (PW) Doppler at inlet of LV and RV (transmitral and transtricuspid flow)

    i. E and A waves of LV and RV inlet (tip of Mitral and Tricuspid valve)

g. Color Doppler of septum from anterior to posterior

h. Left sided pulmonary veins and right superior pulmonary vein can sometimes be seen entering the left atrium in the apical 4 chamber view by color Doppler.

i. 5 Chamber view with anatomy demonstrating LV outflow tract (LVOT) with aortic valve and ascending aorta.

    i. Color Doppler of flow through LVOT. PW in ascending aorta past the aortic valve for VTI calculation.

    ii. Sweep anteriorly and 2D visualization of RV outflow tract (RVOT)

    iii. Color Doppler of RVOT with PW Doppler past the pulmonary valve in MPA

    iv. Evaluation for pulmonary insufficiency and interrogation by CW Doppler.

j. In evaluation of function:

    i. Ejection fraction by biplane Simpson's method using 4 chambers view and 2 chambers LV view.

    ii. Tissue Doppler imaging (TDI) with interrogation at MV annulus at LV free wall, MV annulus at septal wall and tricuspid annulus at RV free wall; calculation of e', a', E/e', MPI (myocardial performance index or Tei index) of LV and RV

    iii. TAPSE (tricuspid annular plain systolic excursion).

k. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).

20. Subcostal view: long axis and short axis (SCL and SCS)

a. SCL view – coronal cut:

    i. Sweep to ensure connection of IVC to right atrium with cross-section of spine.

  ii. Atrial septal 2D evaluation

  iii. Atrial septum color Doppler evaluation and measurement (consider PW Doppler interrogation if acceleration of shunt flow across atrial septal defect or patent foramen ovale; consider M-Mode with color Doppler to evaluate shunting direction of inter-atrial shunt)

  iv. 2D scanning anatomy of SCL axis without color Doppler (establishing atrio-ventricular and ventriculo-arterial connections)

  v. 2D scanning with color of SCL axis from posterior to anterior

  vi. Evaluation of RV and RVOT in 2D motion for qualitative function looking at each segment from RV (inlet, midcavity, apex and RVOT) segmental contraction, especially in the context of pulmonary hypertension (some patients might have segmental wall dysfunction).

  vii. Evaluation by color Doppler of flow in LVOT to Aorta and in RVOT to pulmonary artery with no acceleration. Evaluation for pulmonary insufficiency and interrogation by CW Doppler.

  viii. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).

 b. SCS view – sagital cut:

  i. Evaluation of IVC connection to right atrium

  ii. Color Doppler in IVC at RA junction with low Nyquist velocity

  iii. Color Doppler of subhepatic veins with low Nyquist and PW Doppler of hepatic veins – evaluation of retrograde flow in the subhepatic veins as a sign of abnormal RV diastolic function

  iv. 2D visualization of descending aorta (DesAo)

  v. Color Doppler of DesAo with PW. Note that the Doppler sampling is done at diaphragmatic level with minimal angle of insonation.

  vi. 2D sweep of anatomy in SCS view from IVC/SVC to apex (establishing atrio-ventricular and ventriculo-arterial connections); although this is not the typical view to appreciate LV-RV interaction in terms of septal curvature, some might appreciate indirect signs of RV overload with bowing of septum to LV side. Validated evaluation of septal curvature was described only in the PSA view.

  vii. Visualization of SVC to RA with 2D clip and color Doppler in bicaval view (showing IVC and right SVC junctions to right atrium)

  viii. Atrial septal scanning in SCS view with evaluation of rim size of ASD or PFO in 2D; evaluation of color Doppler with shunt direction through inter-atrial communication if present (low Nyquist velocity)

  ix. Color Doppler of mitral valve, septum for VSD, LVOT and RVOT

  x. 2D evaluation of RVOT

  xi. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).

21. Modified Parasternal Short axis view (mPSA) or PDA view

 a. View of PDA in 2D with connection from pulmonary to aortic side; measurements of PDA (prioritize 2D anatomy measurements of the narrowest point)

b. Color Doppler of PDA: shunt direction
c. CW Doppler of PDA: quantification of shunt gradient velocities
d. M-Mode with Color Doppler for shunt directionality

22. Suprasternal view short and long axis (SSS and SSL)
   a. SSS view:
      i. Visualization of 2D anatomy
      ii. Visualization of RPA course and Color Doppler for acceleration
      iii. Very anterior sweep for pulmonary veins evaluation ("crab view"): PW Doppler of the 4 pulmonary veins at their connection with the left atrium to rule out partial or total anomalous pulmonary venous return
   b. SSL view
      i. Visualization of 2D anatomy of aorta at Ascending Aorta, Transverse Aorta, Isthmus and Descending Aorta.
      ii. Color Doppler of Aorta; CW in the descending Aorta
         1. Note that the PDA may be seen in many views, including this one

Calculation of RV and LV cardiac output

E) Line placements / ECMO Cannulas

Point of care ultrasound for the evaluation of line placements:

Subcostal view: long axis and short axis (SCL and SCS)
   a. SCL view – coronal cut:
      i. Sweep to ensure connection of IVC to right atrium with cross-section of spine.
      ii. Visualization of a line in the IVC (in cross-section) at connection with the right atrium, or an umbilical arterial line in the descending aorta in cross-section.
      iii. Atrial septum evaluation with sweep to ensure to passage of line to the left atrium.
      iv. 2D scanning with and without color of SCL axis from posterior to anterior
      v. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).
   b. SCS view – sagital cut:
      i. Evaluation of IVC connection to right atrium, visualization of line position
      ii. Color Doppler in IVC at RA junction with low Nyquist velocity
      iii. 2D visualization of descending aorta (DesAo) and presence of aortic line
      iv. Color Doppler of DesAo with PW
      v. 2D sweep of anatomy in SCS
      vi. Visualization of SVC to RA with 2D clip and color Doppler in bicaval view (showing IVC and right SVC junctions to right atrium)

          – ensure line from IVC not going to SVC or left atrium via inter-atrial communication

vii. Atrial septal scanning in SCS view with evaluation of rim size of ASD or PFO in 2D; evaluation of color Doppler with shunt direction through inter-atrial communication if present (low Nyquist velocity)

viii. Evaluation of pericardial fluid and measurement at end of diastole (largest filling of ventricle).

c. In the context of pericardial fluid, in Apical 4 chambers view: inflow of mitral and tricuspid valve need to be interrogated by PW Doppler in a compressed time matter for signs of tamponade (evaluate for fluctuation in time of the velocity of inflow). If suspicion of tamponade, PW Doppler interrogation of SVC and IVC needs to be done in the subcostal view for retrograde flow assessment.

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