❤️ Heart Morphogenesis

🫀 Overview

- First functional organ in the embryo
- Begins spontaneous beating by week 4 ⏱️
- Early function is crucial for circulatory support of the growing embryo

---

🔄 Cardiac Looping (Week 4)

📌 Key Concept

- The primitive heart tube loops to establish left-right polarity

🔬 Mechanism

Straight heart tube → Rightward looping (D-looping) → Establishes normal cardiac orientation (atria posterior, ventricles anterior)

⚠️ Clinical Correlation

- Defect in left-right dynein → abnormal asymmetry → Dextrocardia (heart on right side)

💡 Seen in Kartagener syndrome (primary ciliary dyskinesia)

- Associated with:
  - Situs inversus
  - Chronic sinusitis
  - Bronchiectasis

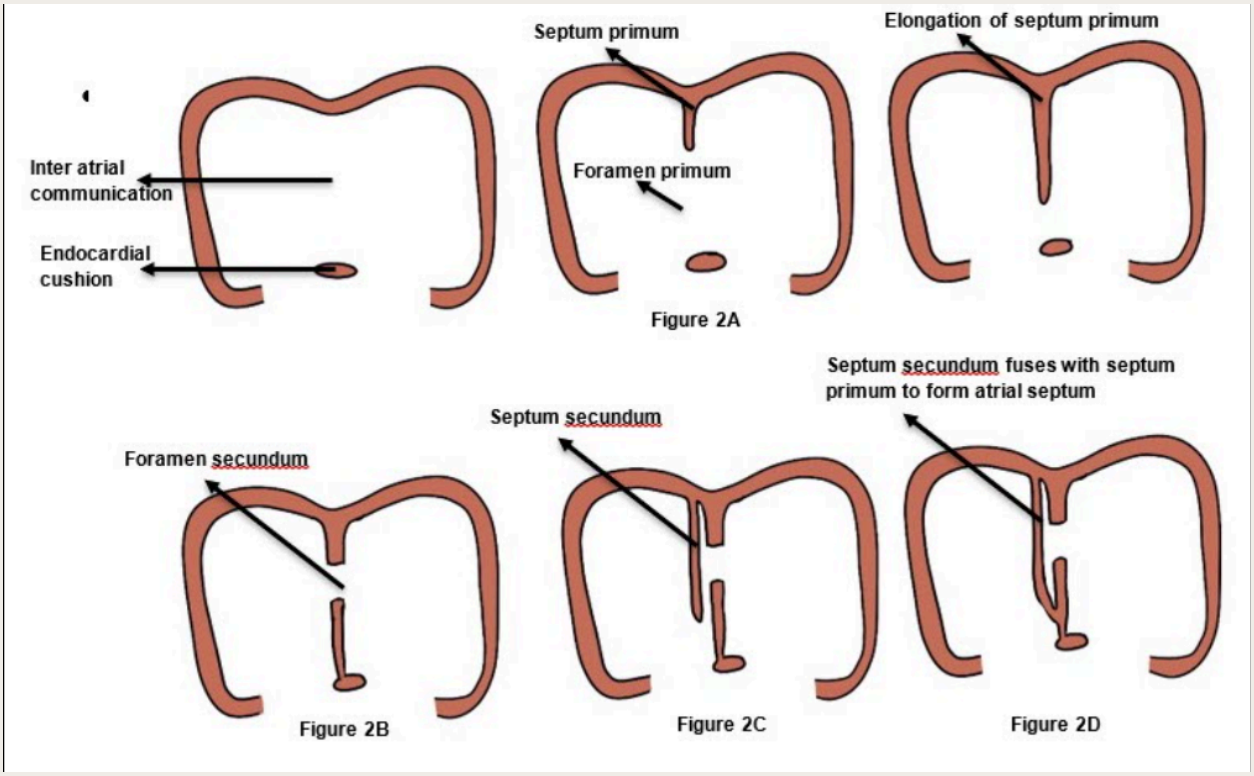
🧠 Septation of the Atria

🔄 Stepwise Formation of Interatrial Septum

Septum primum grows downward toward endocardial cushions → Narrows ostium primum → Apoptosis in septum primum → Formation of ostium secundum (maintains blood flow) → Septum secundum develops to the right of septum primum → Overlaps ostium secundum →

Small opening remains = Foramen ovale

Remaining septum primum forms → One-way valve of foramen ovale 🚪



Source: utmb.edu

🫁 At Birth (Critical Transition)

First breath (collapsed lungs now expand) → ↓ Pulmonary resistance (blood vessels dilate) → ↑ Left atrial (LA) pressure (due to increased blood flow) → ↓ Right atrial (RA) pressure (umbilical cord is clamped, cutting off the high-pressure flow from the placenta) →

Septum primum pushed against septum secundum → Functional closure of foramen ovale

---

🧬 Final Outcome

- Septa fuse during infancy → Forms permanent atrial septum

⚠️ Patent Foramen Ovale (PFO)

📌 Definition

- Failure of septum primum and septum secundum to fuse

📊 Key Facts

- Present in ~25% of population 😲

- Usually asymptomatic

🚨 Clinical Significance

Pathophysiology Flowchart:

Venous thrombus (e.g., DVT) → Travels to right atrium → Passes through PFO (right → left shunt) → Enters systemic circulation → Paradoxical embolism 🧠 (e.g., stroke)

🧠 Exam Pearls

- Think PFO in:
    - Young patient with cryptogenic stroke
    - No obvious arterial source of embolus

- Similar mechanism occurs in Atrial Septal Defect (ASD)

📊 Summary Table

Structure	Function	Key Feature
Septum primum	Initial partition	Forms valve of foramen ovale
Ostium primum	Early opening	Closes as septum primum grows
Ostium secundum	Maintains shunt	Formed by apoptosis
Septum secundum	Secondary partition	Forms foramen ovale
Foramen ovale	Fetal R→L shunt	Closes after birth

💡 Final Takeaways

- Heart starts beating by week 4 ❤️
- Cardiac looping defects → dextrocardia
- Foramen ovale = essential fetal shunt
- Closure driven by pressure changes at birth
- PFO is common but usually silent — can cause paradoxical embolism

---

🫀 Ventricular Septation

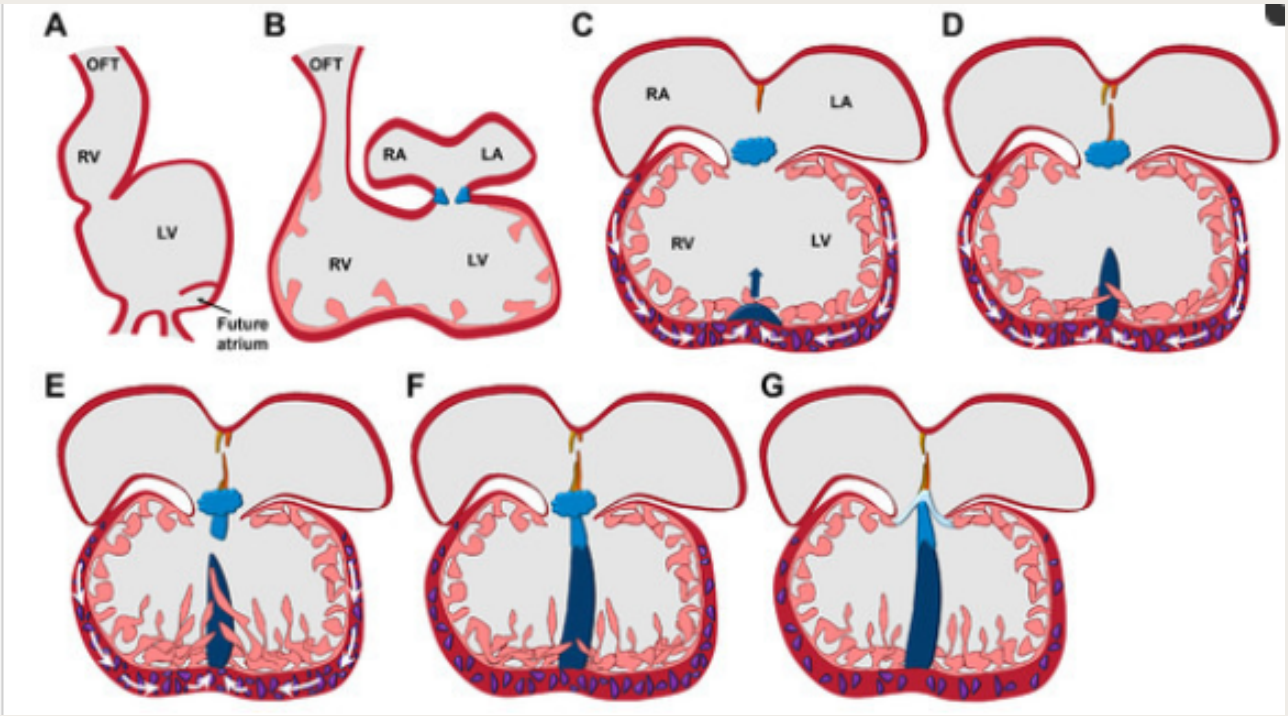
📌 Key Concept

- Formation of the interventricular septum separates right and left ventricles

---

🔄 Stepwise Development

Muscular interventricular septum grows upward from apex → Leaves opening = Interventricular foramen → Neural crest-derived aorticopulmonary septum forms and spirals → Fuses with muscular septum → Formation of membranous interventricular septum → Closure of interventricular foramen ✅



Source: mdpi.com

🧠 Role of Endocardial Cushions

- Critical for:
  - Atrioventricular (AV) separation
  - Atrial septation
  - Membranous part of IV septum

💡 Think of endocardial cushions as the "central building block" of cardiac septation

---

⚠️ Ventricular Septal Defect (VSD)

📌 High-Yield Fact

- Most common congenital heart defect 🚨

🔬 Pathology

- Usually due to defect in membranous septum

🔄 Pathophysiology Flowchart

Left ventricle (high pressure) → Blood shunts to right ventricle → ↑ Pulmonary blood flow → Pulmonary hypertension (Chronic) → Right ventricular hypertrophy → Possible reversal of shunt (Eisenmenger syndrome) 🔵

🧠 Exam Pearls

- Membranous VSD > muscular VSD (most tested)
- Can be associated with:
  - Down syndrome
  - Fetal alcohol syndrome

🔄 Outflow Tract Formation (Conotruncal Development)

📌 Key Concept

- Neural crest cells are essential for proper division of outflow tract

---

🔄 Development Flowchart

Neural crest cell migration → Formation of truncal and bulbar ridges → Ridges spiral and fuse → Formation of aorticopulmonary septum → Division into:

- Ascending aorta
- Pulmonary trunk

⚠️ Conotruncal Defects

Failure of neural crest cell migration leads to:

Defect	Key Feature
Transposition of great arteries	Aorta ↔ Pulmonary artery switched
Tetralogy of Fallot	Pulmonary stenosis + VSD + overriding aorta + RVH
Persistent truncus arteriosus	Single outflow vessel

🧠 Quick Trick

👉 "Neural crest = Conotruncal correctness"

🫀 Valve Development

📌 Origins

Valve Type	Embryologic Origin
Aortic & Pulmonary valves	Endocardial cushions of outflow tract
Mitral & Tricuspid valves	Fused endocardial cushions of AV canal

---

⚠️ Valvular Abnormalities

Can present as:

- Stenosis → Narrowing 🚧
- Regurgitation → Backflow 🔄
- Atresia → Complete absence 🚨
- Displacement → Abnormal position

🧠 Classic Examples

- Tricuspid atresia → absent tricuspid valve
- Ebstein anomaly → displaced tricuspid valve (into RV)

🔄 Ebstein Anomaly

Apical displacement of tricuspid valve → "Atrialization" of right ventricle → Right-sided heart failure

💡 Often associated with:

- Maternal lithium use

💡 Final Takeaways

- Membranous septum = most common site of VSD
- Neural crest cells = crucial for outflow tract division
- Endocardial cushions = central to septa + valves

- Conotruncal defects → always think neural crest problem
- Valve defects can present in multiple structural ways

❤️ Derivatives of Embryonic Structures

🧠 Overview

- The heart develops from multiple embryologic components
- Each contributes to specific adult structures

📊 Embryologic Derivatives Table

🧬 Embryonic Structure	❤️ Adult Derivative

Right common cardinal vein + right anterior cardinal vein	Superior vena cava (SVC)
Posterior, subcardinal, supracardinal veins	Inferior vena cava (IVC)
Right horn of sinus venosus	Smooth part of right atrium (sinus venarum)
Left horn of sinus venosus	Coronary sinus
Primitive pulmonary vein	Smooth part of left atrium
Primitive atrium	Trabeculated parts of both atria
Endocardial cushions	Atrial septum, membranous IV septum, AV valves, semilunar valves
Primitive ventricle	Trabeculated parts of ventricles

Bulbus cordis	Smooth outflow parts of ventricles
Truncus arteriosus	Ascending aorta + pulmonary trunk

🔄 Conceptual Flow

Primitive heart tube forms → Differentiates into regions (atrium, ventricle, bulbus cordis, truncus arteriosus) → Neural crest + endocardial cushions contribute to septation → Mature cardiac chambers and great vessels formed ❤️

🧠 Key Integration Points

❕Smooth vs Trabeculated Parts

Chamber	Smooth Part Origin	Trabeculated Part Origin
Right atrium	Sinus venosus (right horn)	Primitive atrium
Left atrium	Primitive pulmonary vein	Primitive atrium
Ventricles	Bulbus cordis	Primitive ventricle

💡 Exam trick:

- "Smooth = venous inflow or outflow tract"
- "Trabeculated = primitive chamber"

2️⃣ Sinus Venosus Derivatives

Sinus venosus →

Right horn enlarges → Becomes smooth right atrium (sinus venarum)

Left horn regresses → Forms coronary sinus 🫀

3️⃣ Endocardial Cushion Importance 🚨

Endocardial cushions → Form AV septum → Contribute to:

- Atrial septum
- Membranous IV septum
- AV valves (mitral, tricuspid)
- Semilunar valves

💡 Defects → AV septal defects (common in Down syndrome)

4️⃣ Outflow Tract Derivatives

Flowchart:

Truncus arteriosus → Divided by aorticopulmonary septum → Forms:

- Ascending aorta
- Pulmonary trunk

⚠️ Clinical Links

- SVC anomalies → think cardinal veins
- IVC anomalies → complex venous embryology
- Coronary sinus defects → left sinus venosus issue
- Conotruncal defects → truncus arteriosus + neural crest problem
- AV septal defects → endocardial cushion defect

💡 Memory Tricks

- "Sinus = Smooth" → sinus venosus → smooth RA
- "Pulmonary vein = LA smooth"
- "Bulbus = خروج (outflow)" → smooth ventricular outflow
- "Truncus = trunk vessels" (aorta + pulmonary)

🧠 Takeaways

- Right sinus venosus → smooth RA
- Left sinus venosus → coronary sinus
- Primitive atrium/ventricle → trabeculated parts
- Bulbus cordis → smooth ventricular outflow
- Truncus arteriosus → great vessels
- Endocardial cushions = septa + valves

🌟 Fetal Circulation

🫀 Fetal Oxygenation Basics

- Umbilical vein:
  - PO_2 ≈ 30 mmHg
  - ~80% O_2 saturated (highest in fetus)
- Umbilical arteries:
  - Carry deoxygenated blood back to placenta

💡 In fetal life, placenta = lungs 🌬️

🔄 The 3 Essential Fetal Shunts

1. Ductus Venosus (Liver Bypass)

Umbilical vein → Ductus venosus → IVC → Right atrium

📌 Function: Bypasses hepatic circulation → preserves oxygen-rich blood

---

2. Foramen Ovale (Right → Left Atrial Shunt)

IVC (oxygenated blood) → Right atrium → Foramen ovale → Left atrium → Left ventricle → Ascending aorta → brain & heart 🧠❤️

📌 Function: Sends best oxygenated blood to vital organs

---

3. Ductus Arteriosus (Lung Bypass)

SVC (deoxygenated blood) → Right atrium → Right ventricle → Pulmonary artery → High pulmonary resistance 🚫 → Blood diverted via ductus arteriosus → Descending aorta

📌 Function: Bypasses non-functioning fetal lungs

🔄 Complete Fetal Circulation Flowchart (Exam Gold)

Placenta → Umbilical vein (O_2-rich) → Ductus venosus → IVC → Right atrium → Split flow:

i. Foramen ovale → LA → LV → Ascending aorta → brain/heart → Umbilical arteries → Placenta

ii. RA → RV → Pulmonary artery → Ductus arteriosus → Descending aorta → Umbilical arteries → Placenta

---

🏁 Changes at Birth

First breath → ↓ Pulmonary vascular resistance → ↑ Blood flow to lungs → ↑ Left atrial pressure → ↓

Right atrial pressure → Foramen ovale closes → Fossa ovalis

🔬 Ductus Arteriosus Closure Mechanism

- ↑ Oxygen (from breathing)
- ↓ Prostaglandins (placenta removed)
- Result: Ductus arteriosus constricts → Forms ligamentum arteriosum

---

💊 Pharmacology Integration

Close PDA:

- Indomethacin
- Ibuprofen
- Acetaminophen

👉 Mechanism: ↓ Prostaglandins → PDA closes

Keep PDA Open:

- Prostaglandin E1 / E2

👉 Used in duct-dependent congenital heart diseases 🚨

🧠 Mnemonic:

"Endomethacin ends the PDA"

📊 Fetal → Postnatal Derivatives

Fetal Structure	Postnatal Derivative	Key Note

Ductus arteriosus	Ligamentum arteriosum	Near left recurrent laryngeal nerve
Ductus venosus	Ligamentum venosum	Liver remnant
Foramen ovale	Fossa ovalis	Interatrial septum
Allantois → Urachus	Median umbilical ligament	Bladder → umbilicus
Umbilical arteries	Medial umbilical ligaments	Paired
Umbilical vein	Ligamentum teres hepatis	In falciform ligament

---

⚠️ Clinical Correlation: Patent Ductus Arteriosus (PDA)

🔄 Pathophysiology

Aorta (high pressure) → Blood flows into pulmonary artery → ↑ Pulmonary blood flow → Pulmonary hypertension

Long term: Reversal of foramen ovale (Eisenmenger) → cyanosis 🔵

🧠 Final Takeaways

- 3 shunts = DV → FO → DA
- FO closure = pressure change
- DA closure = O_2 ↑ + prostaglandins ↓
- NSAIDs → close PDA, prostaglandins → keep open
- Placenta = oxygen source, not lungs

-> The End <-