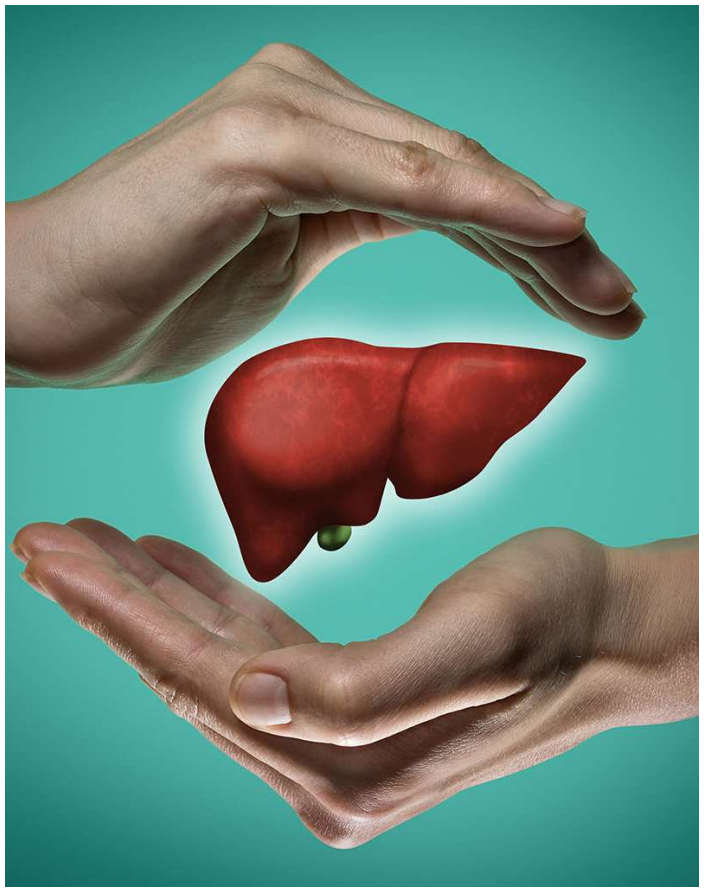


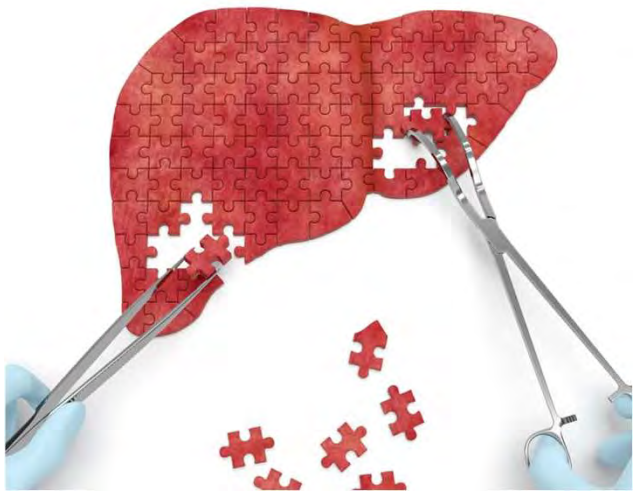
Anesthetic Considerations and Challenges for Orthotopic Liver Transplantation

DANIELLE M. LION, DNP, APN, CRNA

UNIVERSITY HOSPITAL, NEWARK NJ

Learning Objectives

1. Identify key preoperative considerations for liver transplant candidates.
2. Appreciate the anesthetic challenges and goals unique to each surgical phase of liver transplantation.
3. Utilize hemodynamic monitoring devices to optimize volume resuscitation, cardiac output and end-organ perfusion.
4. Anticipate and respond to hemodynamic changes and metabolic disturbances.
5. Discuss transfusion strategies and the role of point-of-care testing, such as TEG.
6. Recognize common complications and strategies to enhance care.
7. Emphasize the importance of effective communication and multidisciplinary collaboration during liver transplant cases.



Dedication & Thanks

My Patients

- Mrs. Elizabeth Coral & Family

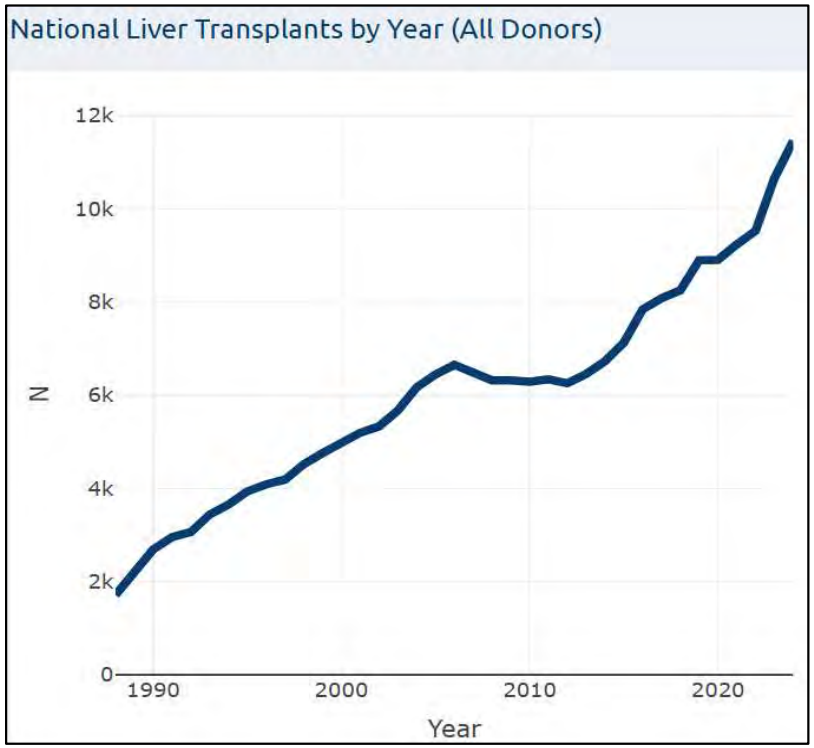
Our Dedicated Liver Transplant Anesthesia team (my mentors) & our Surgical Transplant Team

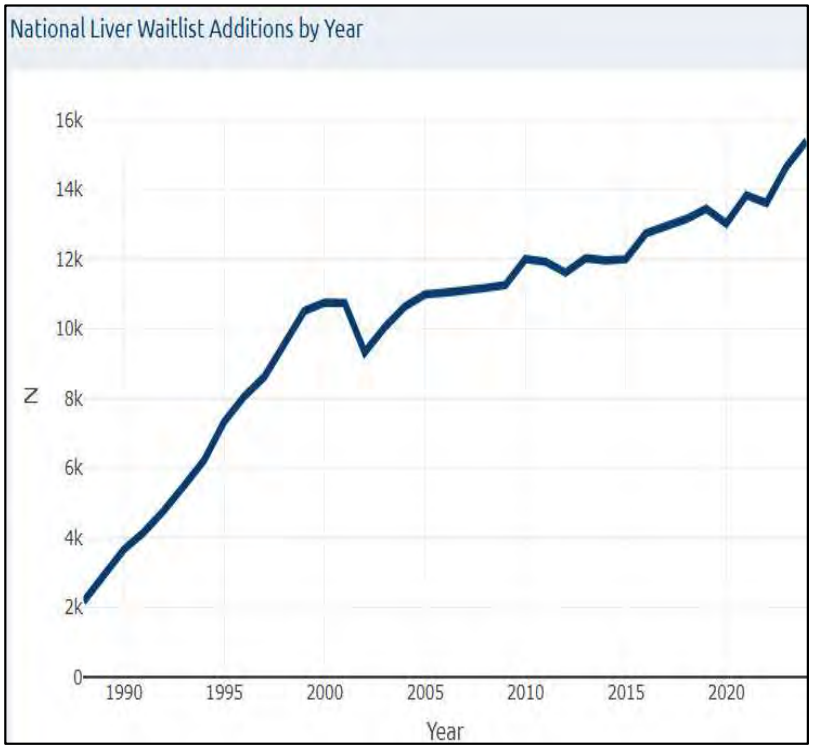
- Drs. Gubenko, Botea, Eloy & Chaudhry (top R→L)
- Drs. Lee Riddle, Amin, Guarrara, Paterno & Lunsford (bottom R→L)

Liver Transplant Statistics

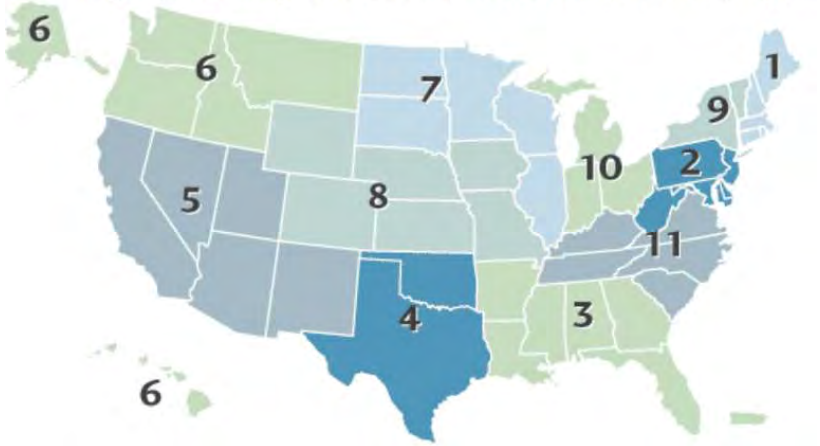
- **OLT is the only definitive treatment for irreversible acute or chronic ESLD**
- Liver grafts obtained from living & cadaver donors
  - After brain death (DBD), or after circulatory death (DCD)
- Survival rates post-transplant ↑'d dramatically in recent years
  - 1 year: 88-91.8%
  - 3 year: 83-88%
  - 5 year: 76.1%
- >10,000 liver transplants in the US in 2023-2024
- Nearly 10,000 candidates remain on the waitlist
- Wait time: 3 month (40%), 6 month (46%), 1 year (55%)
- Pre-transplant mortality = 12%
- 1 in 4 patients will die or become too sick for transplant

The United Network of Organ Sharing (UNOS) National Data





Region 11 : Kentucky, North Carolina, South Carolina, Tennessee, Virginia



Virginia Organ Waitlist by MELD Score	Liver
All Types	**273**
Not Applicable	0
Liver Status 7 (Inactive)	37
Liver MELD / PELD <15	107
Liver MELD / PELD 15-19	73
Liver MELD / PELD 20-24	43
Liver MELD / PELD 25-29	8
Liver MELD / PELD 30-34	2
Liver MELD / PELD 35+	3

Virginia

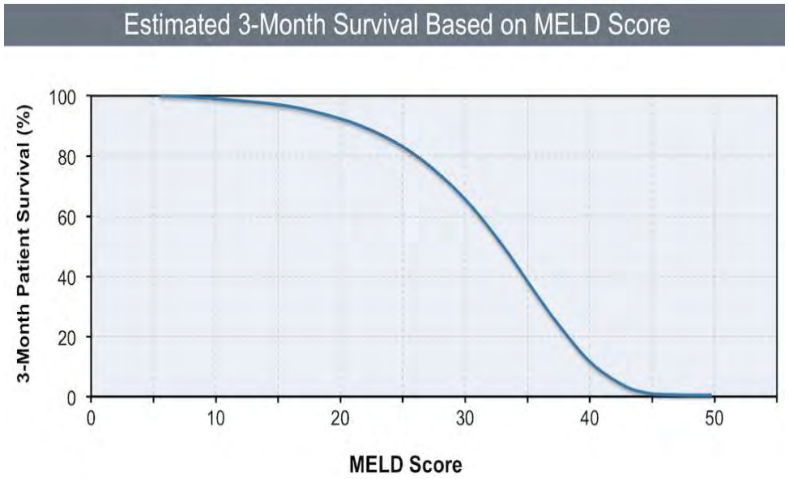
- Active OPOs 1
- Active TXCs 7

LifeNet Health®

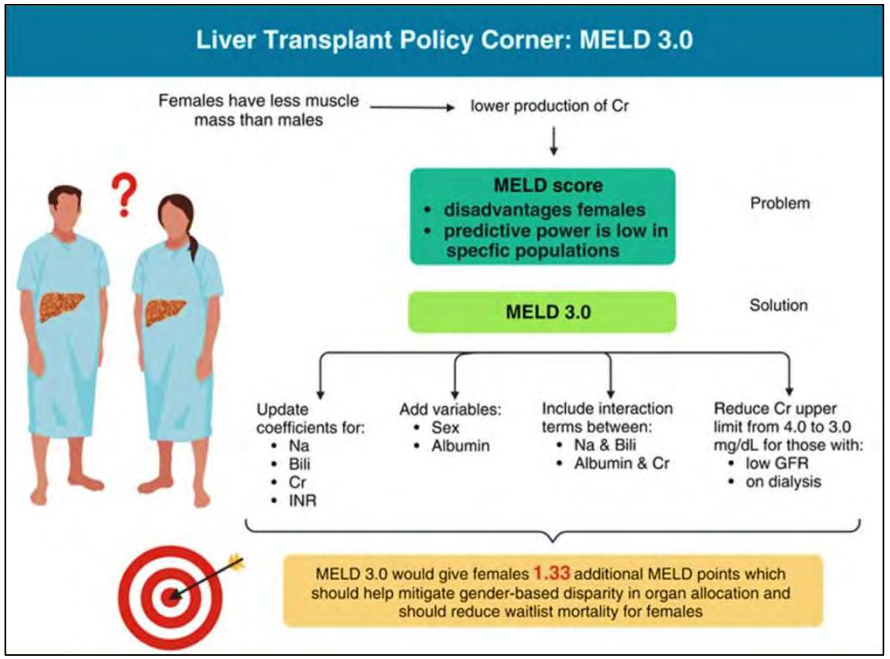
Liver Transplants in VA (2019-2024)	2024	2023	2022	2021	2020	2019
All Centers	269	288	253	246	214	197
VAMC-TX1 VCU Health System Authority, VCUMC	189	205	168	164	135	87
VAUV-TX1 University of Virginia Health Sciences Center	80	83	85	82	79	110

Model for End Stage Liver Disease (MELD)-Na score

3-month mortality, %	MELD score
1.9 - 3.7	< 9
6 - 20	10 - 19
19.6 - 45.5	20 - 29
52.6 - 74.5	30 - 39
71 - 100	> 40



- Score to predict ESLD disease severity & survival
- Serum bilirubin, INR, creatinine & Na+
- Score range 6-40
- Avg National MELD at time of transplant = 33
- Exemption points to patients with intrinsic disease (i.e. HCC)
- Exception points = (avg MELD at transplant) - 3
  - Ex: Patient with HCC: per labs, MELD score = 15
  - average MELD at transplant for center = 31
  - MELD exception points = (31-3) = 28
  - Patient listed with a MELD of 28 rather than 15

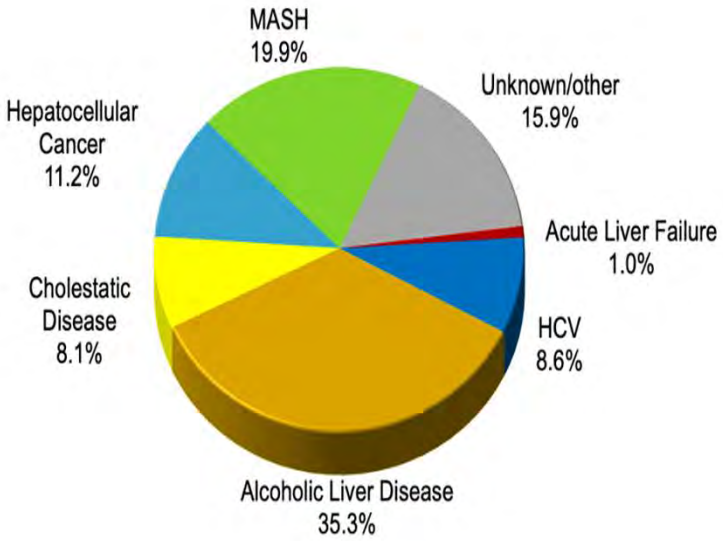


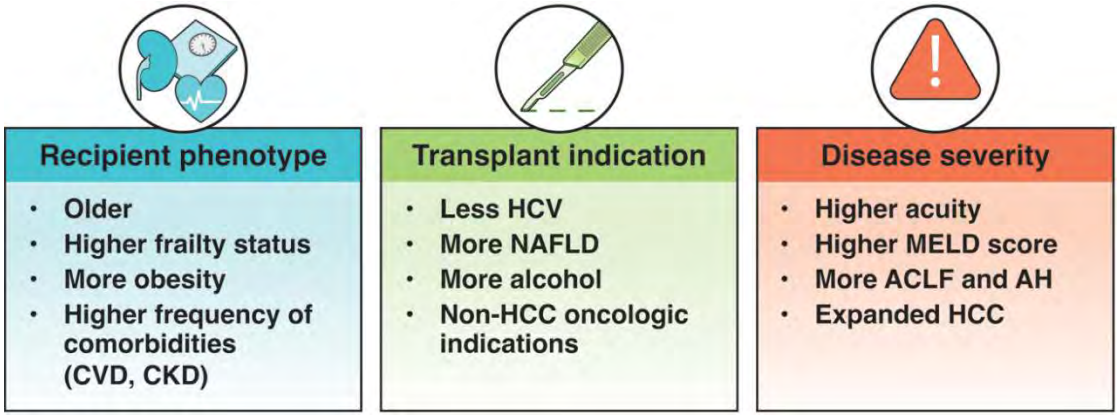
MELD Score Updates

- MELD originally adopted by UNOS for its accuracy & objectivity c/t Child-Pugh
- MELD disadvantages certain populations?
- MELD 3.0 (NEW in 2023):
  - Serum albumin & female sex added as variables
  - Caps creatinine at 3mg/dL
  - Uncaps MELD score to reflect disease severity & urgency for scores >40
  - Improves mortality risk stratification, organ allocation, equity & efficiency

(Mehta, et. al, 2023).

Common Indications & Current Patient Trends for Liver Transplantation



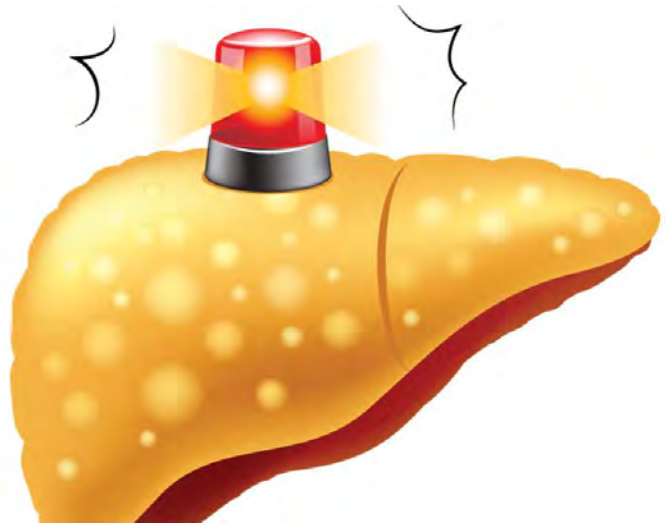


Kwong, et al., 2024

Terrault, et al., 2023

Absolute Contraindications for OLT

- Severe cardiac or pulmonary disease
- Fulminant hepatic failure with ICP > 50 mm Hg
- Hepatocellular carcinoma with metastatic spread
- Pulmonary artery pressures >50mmHg
- Intrahepatic cholangiocarcinoma, hemangiosarcoma
- Extrahepatic malignancy
- Persistent noncompliance
- Uncontrolled sepsis
- AIDS
- Lack of adequate social support system
- Ongoing alcohol or illicit substance use (?)



Hepatic Anatomy

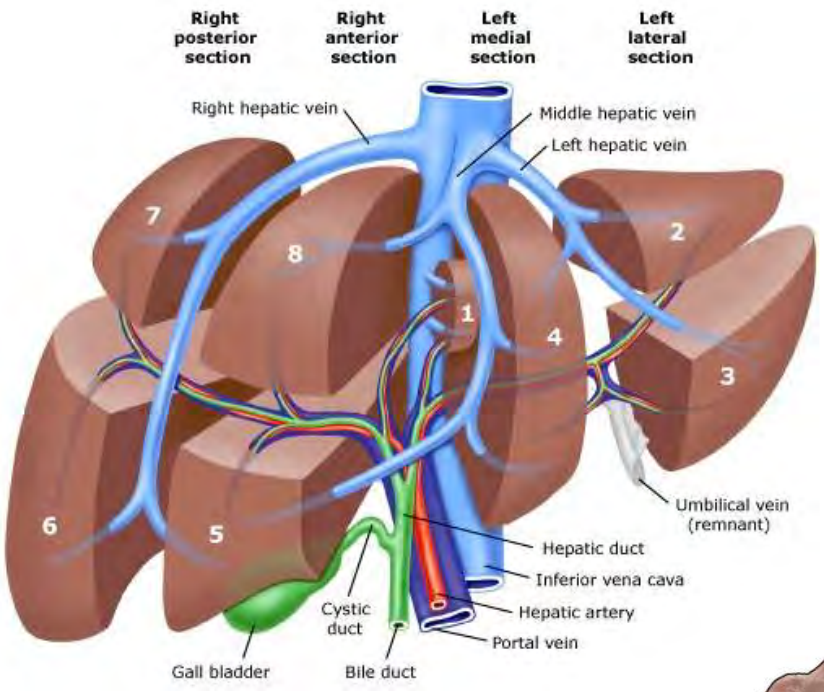
Surgical Divisions (Couinaud's Classification)

- 8 functionally independent segments with distinct vascular inflow & biliary drainage
  - Right & left hemi-livers
  - 4 sectors (vertical planes of hepatic veins)
  - 8 segments (transverse bifurcation of portal vein)

Portal Triad

- Hepatic artery
- Portal vein
- Common hepatic duct

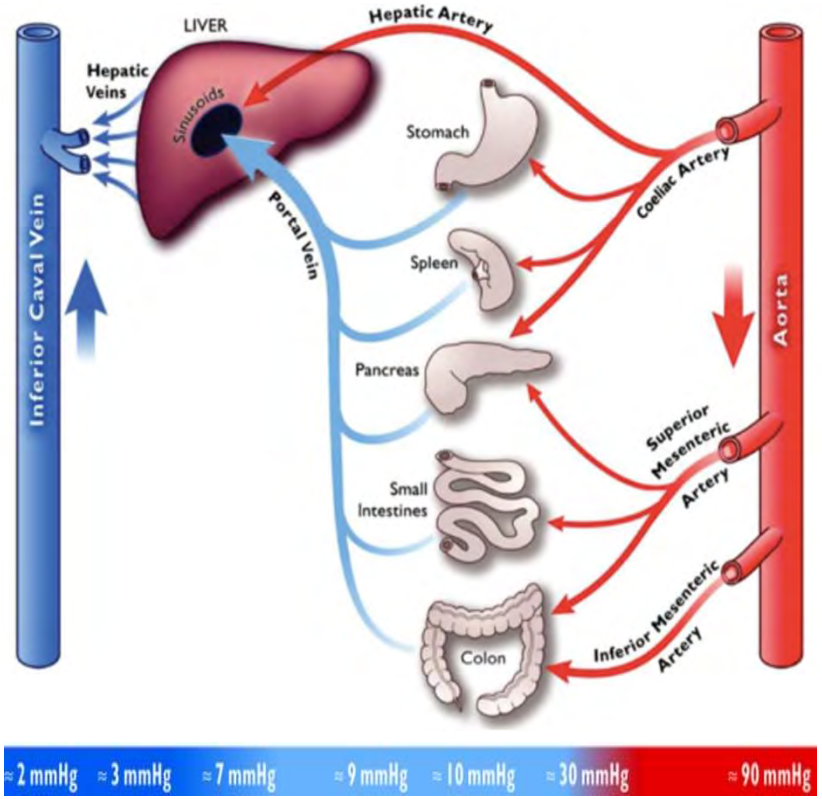
(Stammers, 2018)



(Marcus, et. al., 2024)

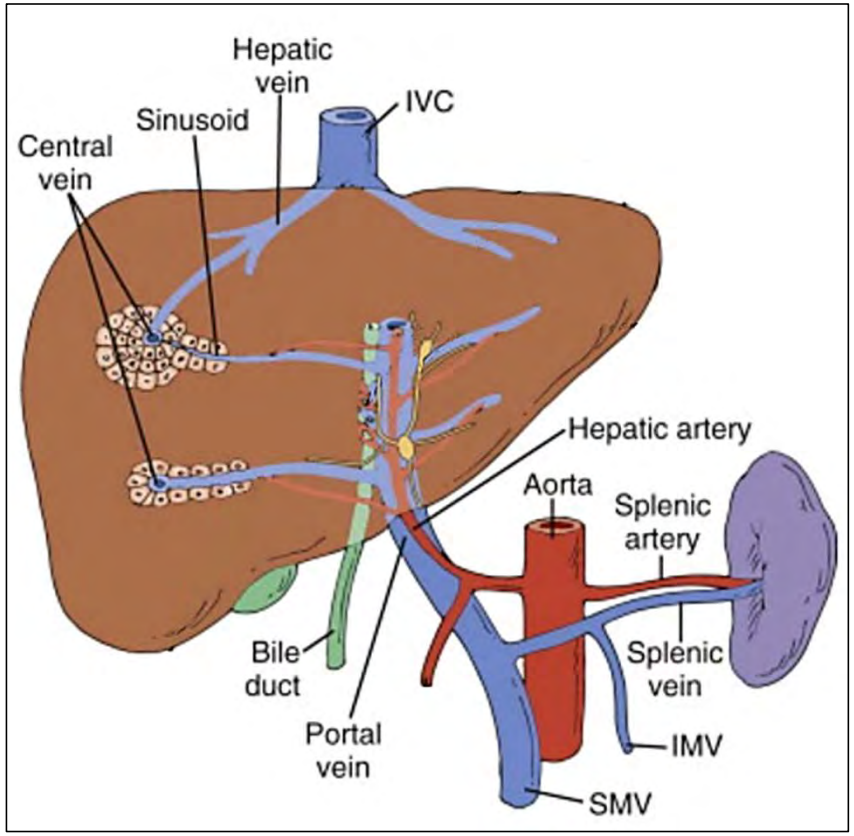
Hepatic Blood Flow

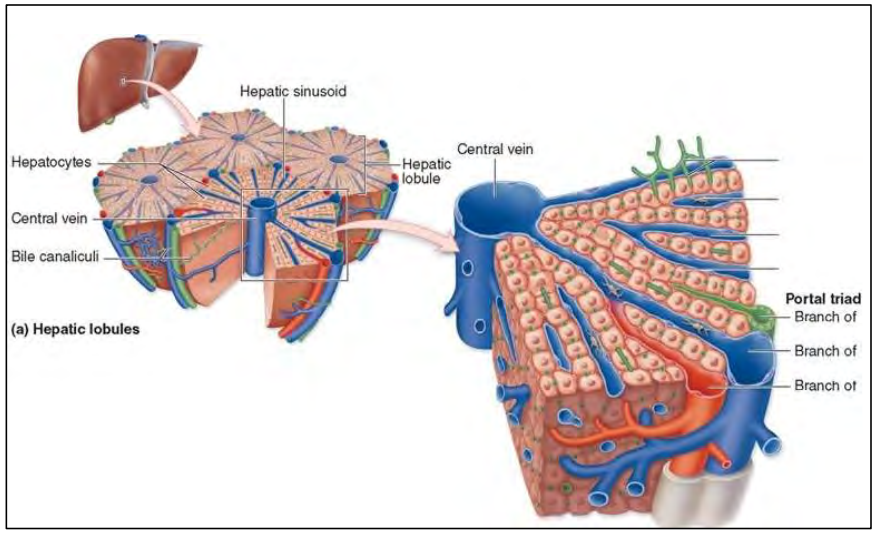
- **Hepatic Artery (HA)**
  - 25% total hepatic blood flow
- **Portal Vein (PV)**
  - 75% total hepatic blood flow
  - Partial deoxygenated from digestive organs
  - Valveless
  - High flow, Low pressure/low resistance
  - Portal HTN → retrograde flow, varices & collateral vessel formation
  - HA & PV become smaller arterioles & venules before converging & emptying → sinusoids of the liver

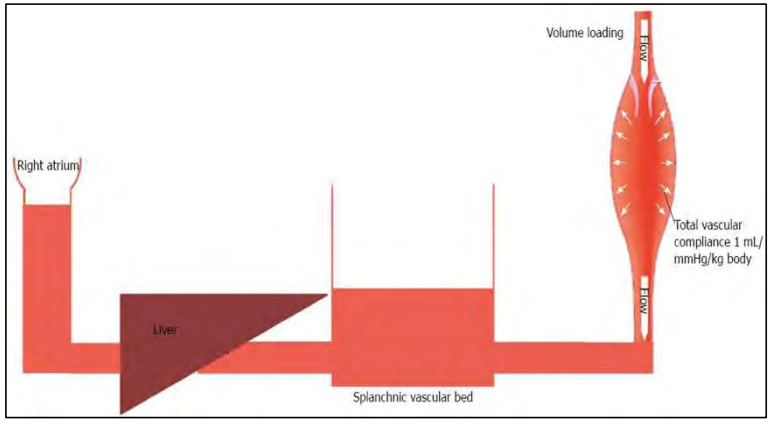


Gelman & Mushlin, 2004

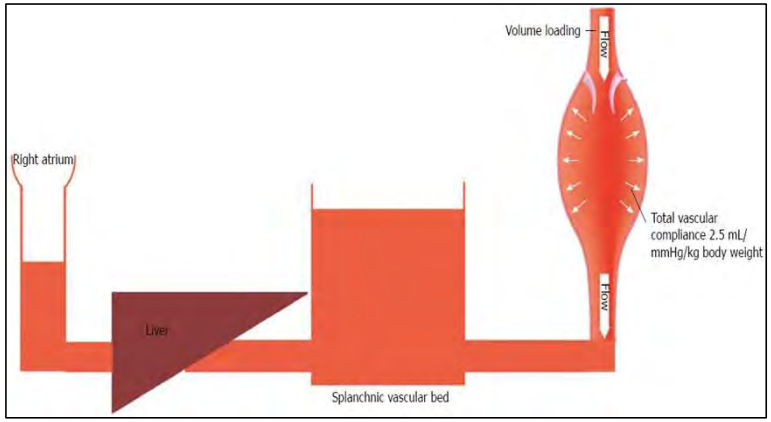
Hepatic Blood Flow







Fluid loading in a healthy patient (Mukhtar & Dabbos, 2016).



Fluid loading in a cirrhotic patient (Mukhtar & Dabbos, 2016).

Hepatic Blood Flow

Portal Venous Pressure

- Blood flow from splanchnic organs → portal vein
- Resistance to portal vein blood inflow or outflow

Pressure Gradients

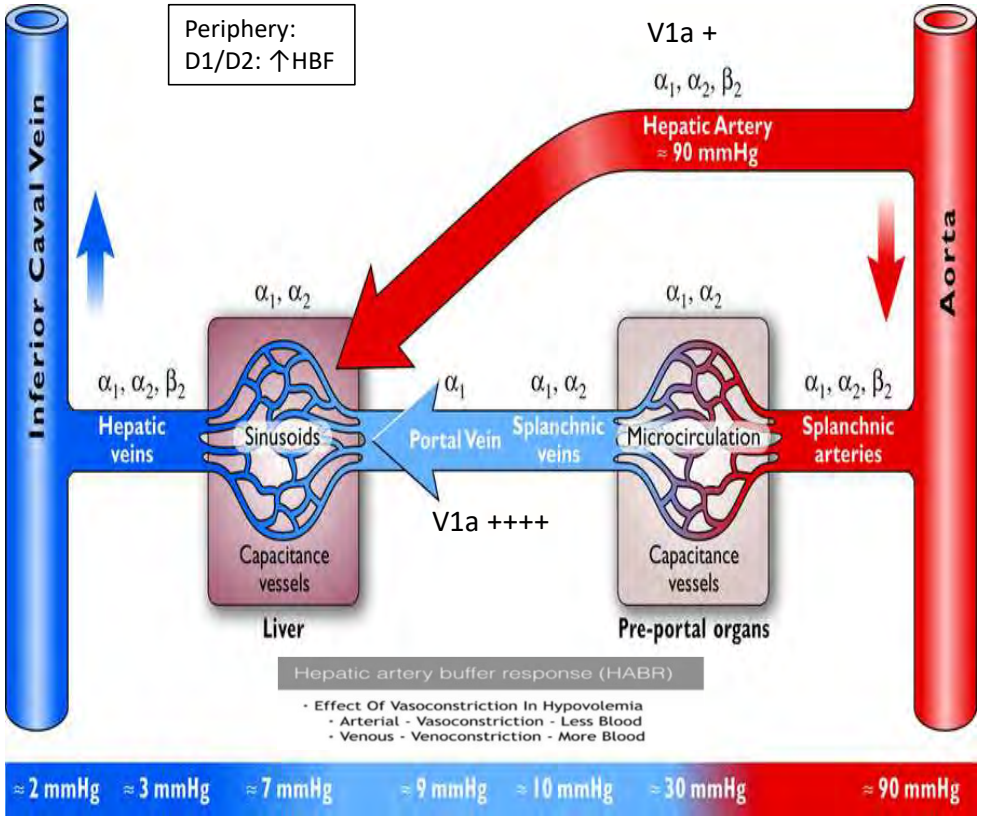
- Venous systems relies on pressure gradients to move blood to maintain forward flow from splanchnic → systemic circulation
- ↑ Hepatic venous pressure gradient (HVPG) = Portal HTN

Hepatic Venous Compliance

- Pre-portal, portal & sinusoids = Venous capacitance vessels
- Contain only α-adrenergic receptors responsible for compliance of hepatic venules → preload, CO & liver reservoir

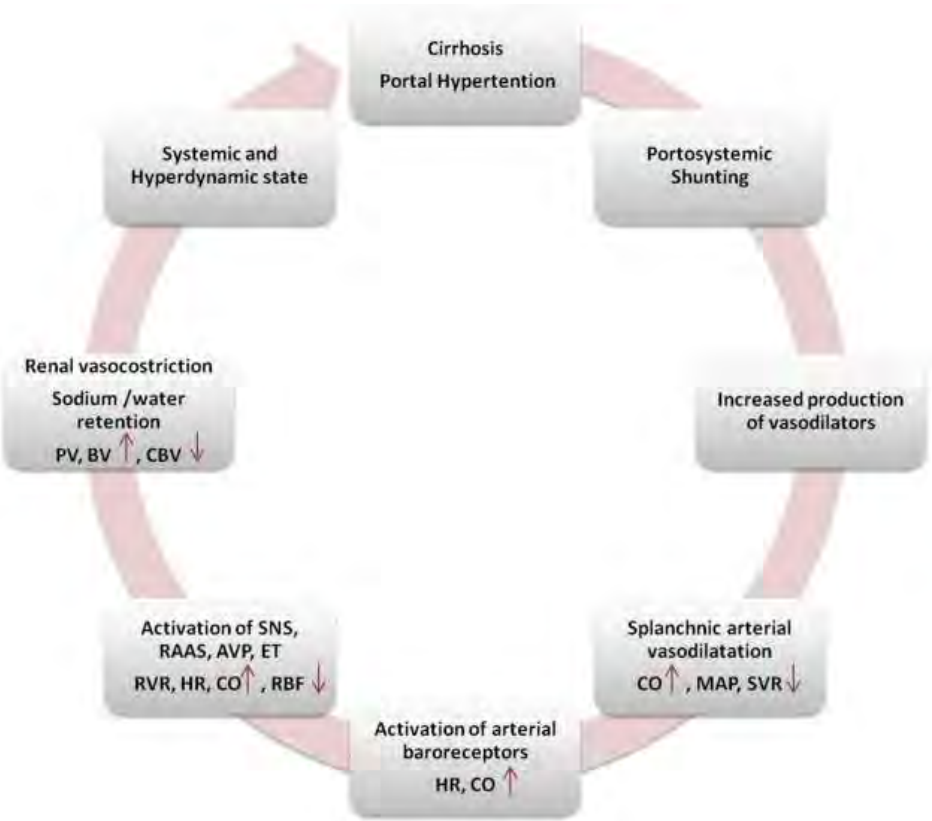
Hepatic Blood Flow (HBF)

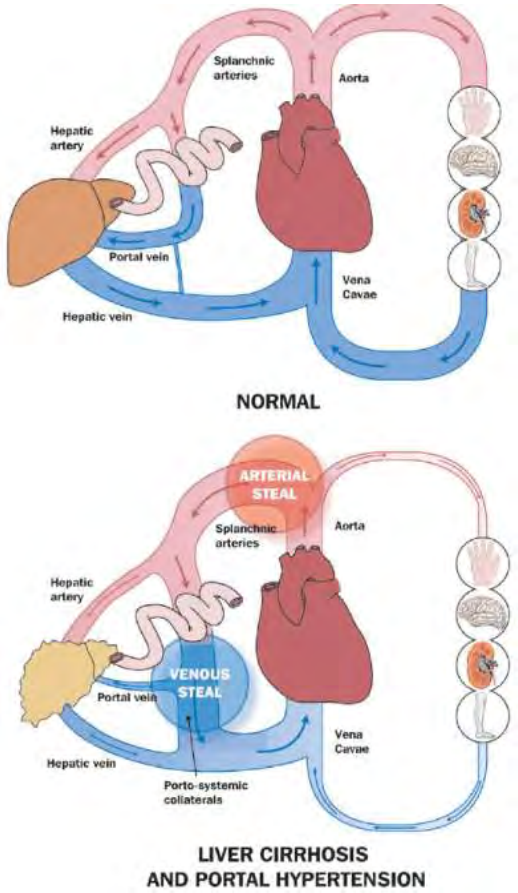
Hepatic Artery & Splanchnic arteries	▪ Flow determined by resistance from arterial tone ▪ α1, α2, β2, **minimal [vasopressin receptors, V1a]** ▪ HBF: α1 ↓, β2 ↑, V1a ↓/0?
Pre-Portal & Splanchnic arterioles	▪ Flow determined by resistance from splanchnic veins ▪ **only α receptors** (α1 & α2) ▪ HBF: α1 may ↑/↓/0
Portal Vein	▪ Flow determined by pre-portal flow & liver resistance ▪ **only α1, High [V1a]** ▪ HBF: α1 usually ↓, V1a ↓
Intrahepatic & Sinusoidal Flow	▪ Flow determined by portal flow and post-hepatic resistance ▪ **only α receptors** (α1 & α2), Low [V1a] ▪ HBF: α1 usually ↓, V1a ↓ (by up to 30%)
Hepatic Veins	▪ Little resistance to flow as IVC pressure normally low (CHF, PPV can ↑ resistance) ▪ α1, α2, β2 ▪ HBF: α1 ↓ (decreases liver drainage)



Adapted from Gelman & Mushlin, 2004

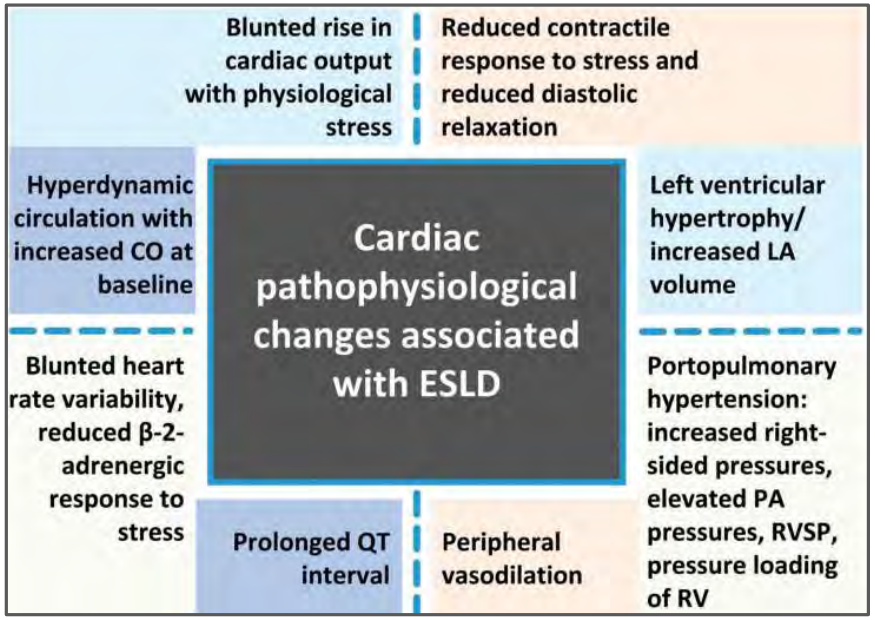
Hyperdynamic Circulatory Syndrome



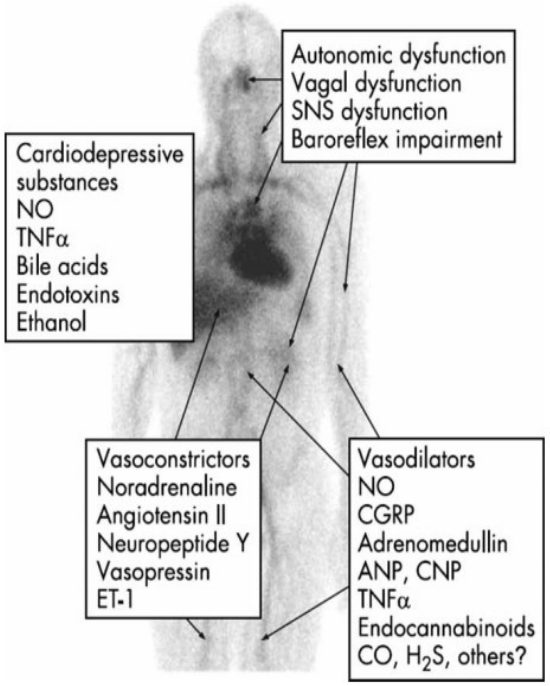


(Newby & Hayes, 2002)

Clinical Features of Hyperdynamic Circulation

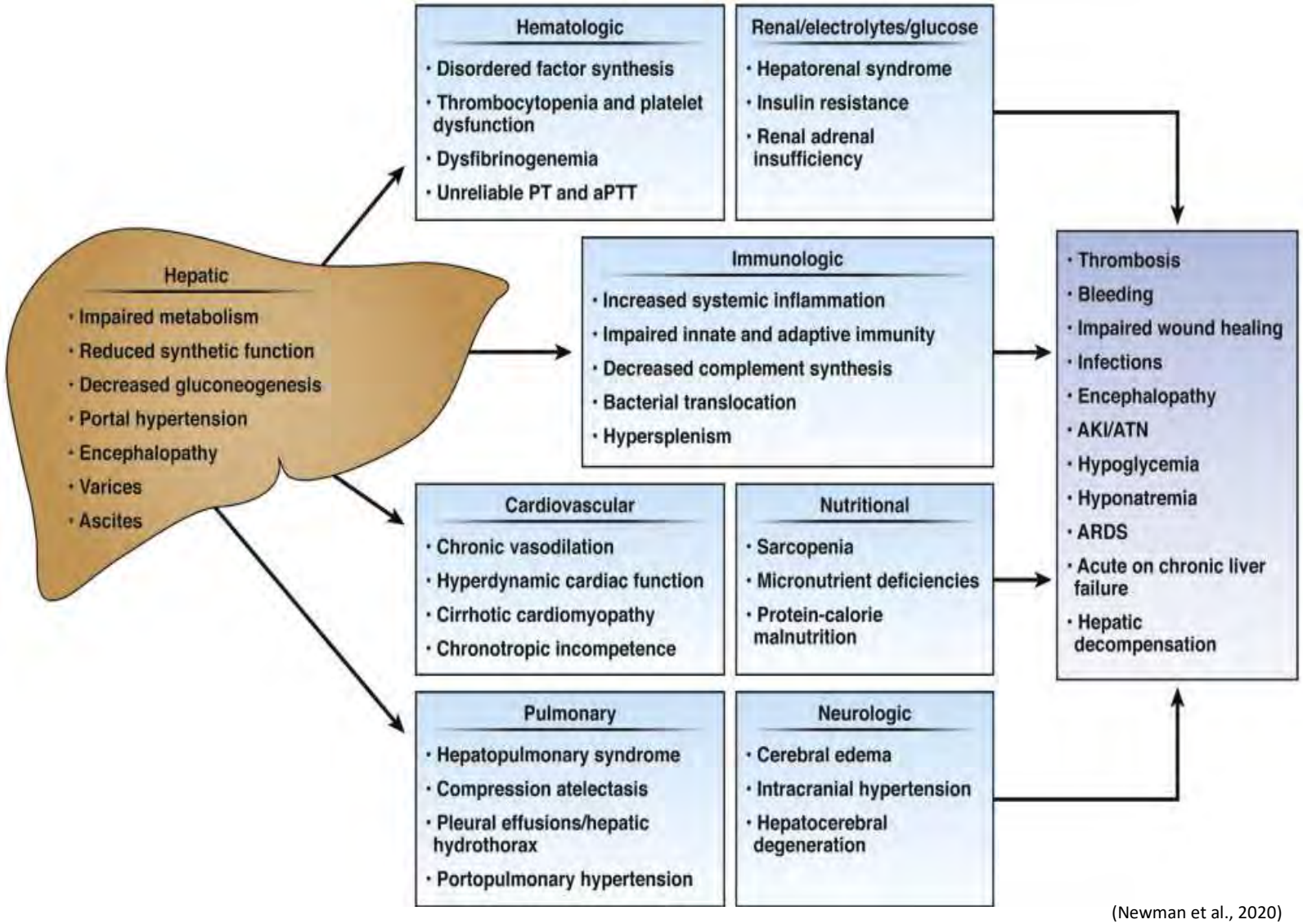


(Cekman & Uslu, 2024)



(Henriksen & Møller, 2009)

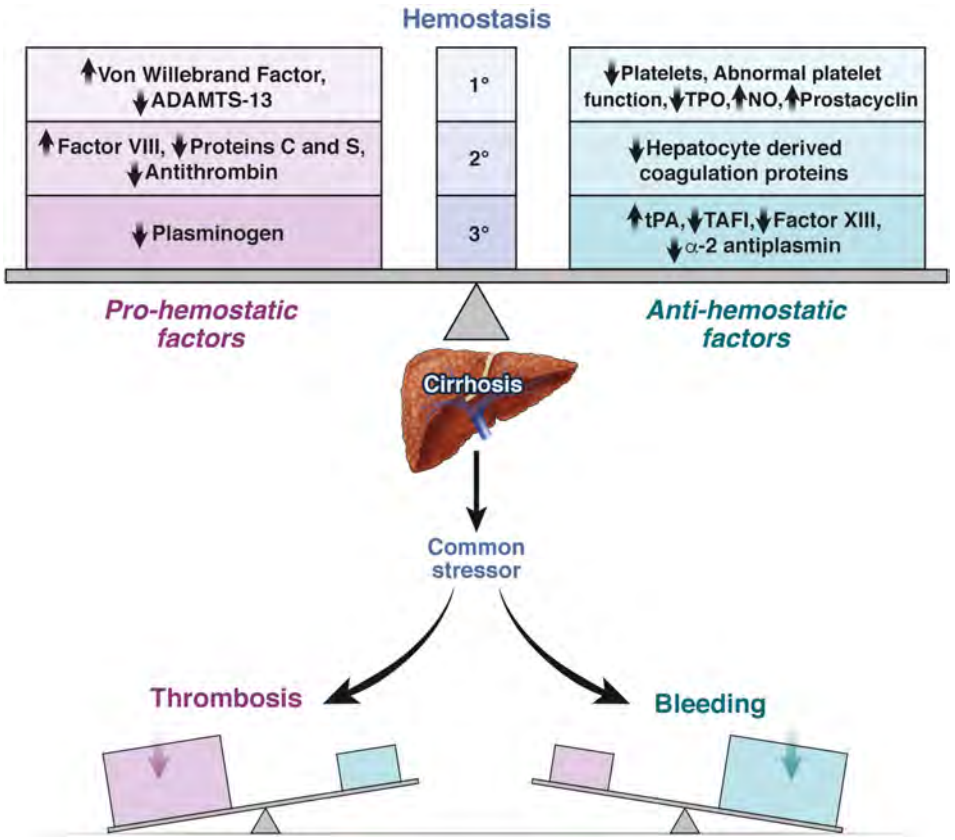
Metabolic, Anatomic, and Physiological Changes in Cirrhosis



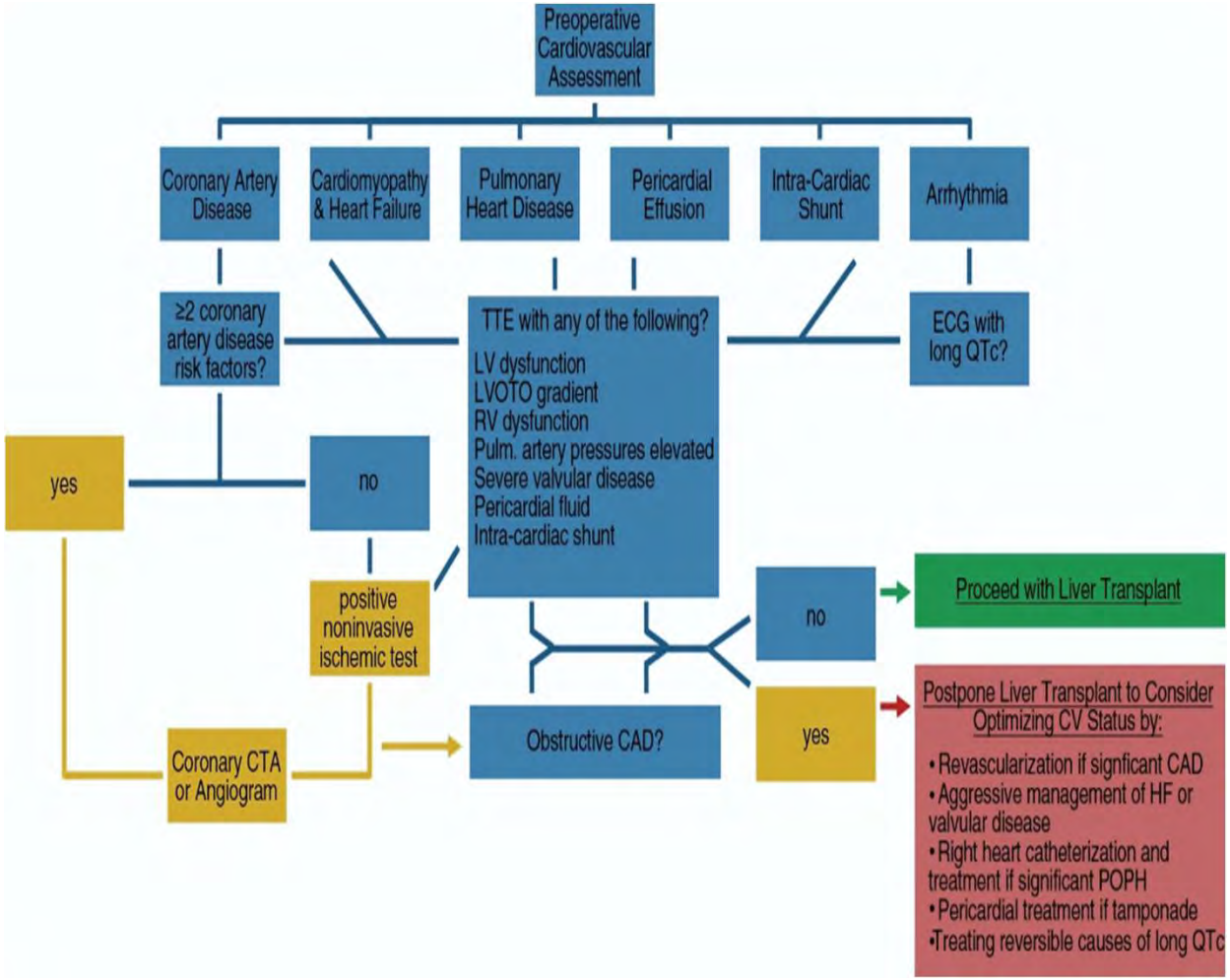
(Newman et al., 2020)

Coagulopathies

- A fragile equilibrium between prothrombotic and antithrombotic factors
- Patient equally susceptible to BOTH hemorrhage & thrombosis
- Risk of tipping towards either extreme depending on stressors
- Common stressors = surgery, AKI, invasive procedure, acute decompensation & infections)



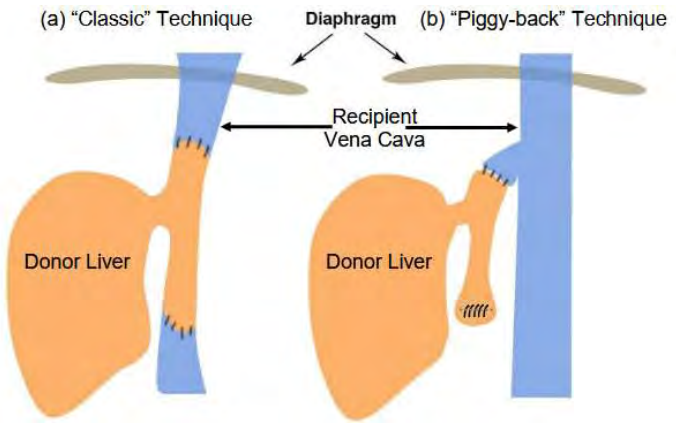
(Intagliata, et al., 2021)



(Rossetto, et. al., 2012)

OLT Preoperative Assessment

- CBC, BMP, PT/PTT, INR, fibrinogen, liver enzymes, ABG
- TEG
- CXR
- Extensive cardiac work-up
  - EKG
  - TTE/TEE
  - Stress Echocardiography
  - PCI/revascularization (if indicated)
- Pre-op optimization & correction of all electrolyte abnormalities
- Pulmonary Function Tests/Spirometry, if indicated
- Treat active infections



(Deshpande & Chadha, 2018)

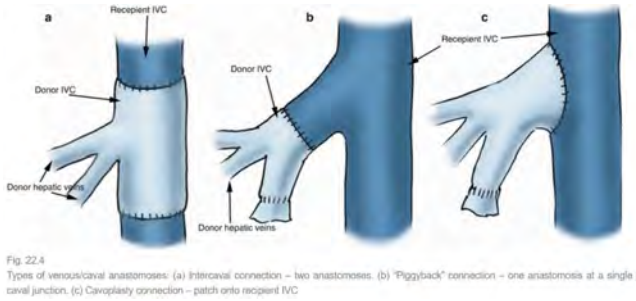


Fig. 22.4
Types of venous/caval anastomoses: (a) Intercaval connection – two anastomoses. (b) "Piggyback" connection – one anastomosis at a single graft-recipient caval junction. (c) Cavoplasty connection – patch onto recipient IVC

(Radiology Key, 2016)

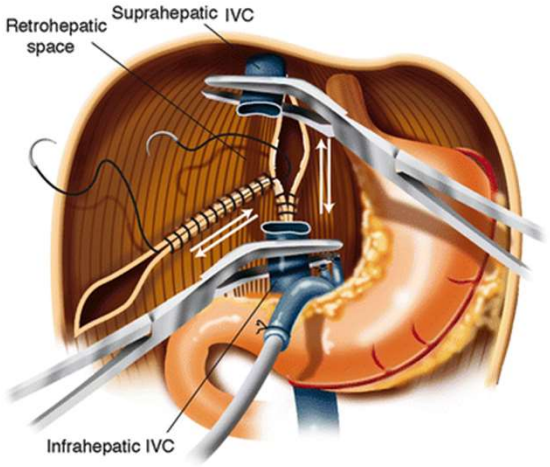
Surgical Technique: Conventional vs. Piggyback

Classic Caval ("Bicaval")

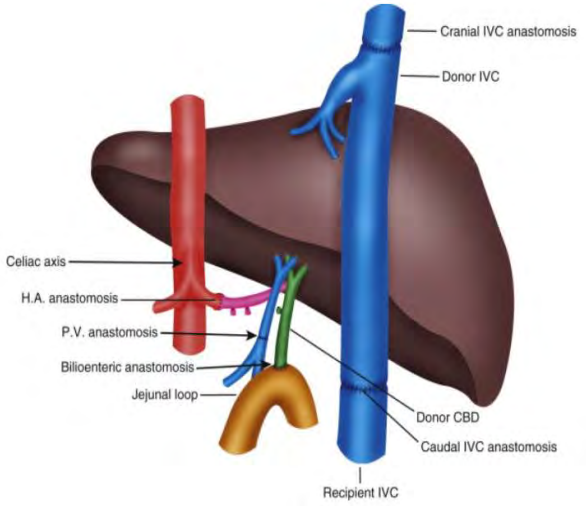
- Resection of recipient native liver + retrohepatic IVC
- Implantation of an interposed donor IVC + liver graft
- Requires full clamping of recipient suprahepatic & intrahepatic IVC

Piggyback Technique

- Most commonly technique
- Preserves recipient IVC
- Anastomosis of donor IVC → recipient hepatic veins
- Only partial caval clamp required, maintains some venous return
- ↓ operating time, ↓ transfusion, ↓ veno-venous bypass
- ~13% cases converted to conventional/VVB



(Abdominal Key, 2017)



(Drzezo, 2019)

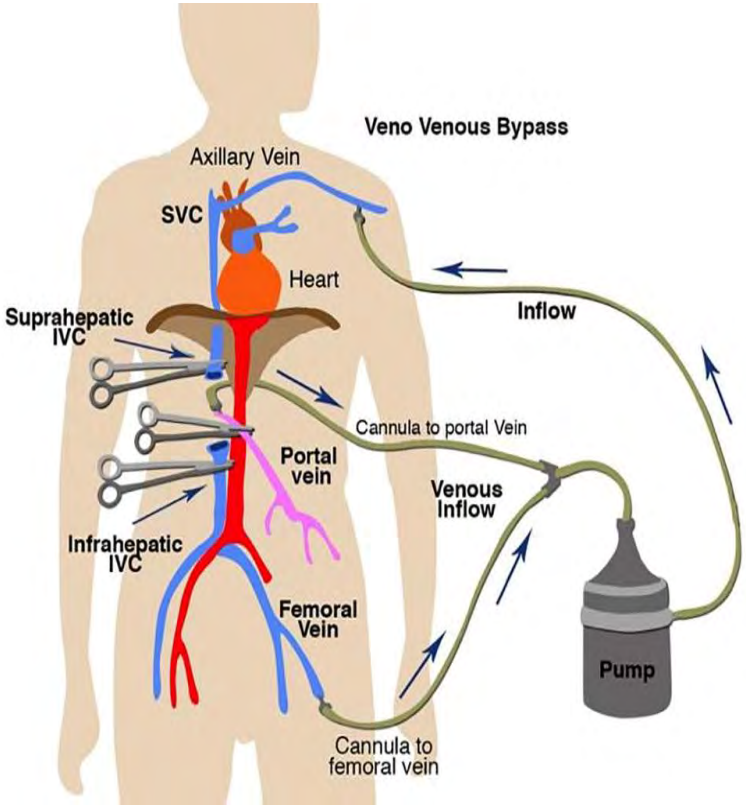
Conventional "Caval" Technique for OLT

- Used with or without veno-venous bypass
- Cross-clamping → drastic drop in preload (~50%)
  - Preload dependent on collateral circulation
- Profound hypotension during IVC clamp → need VVB to maintain preload
  - MAP ↓by 30%, ↓ CI by 50% over 5 min
  - VVB Generally needed in higher MELD scores
- ↑ collaterals may require VVB to decompress portal circulation
- Only option for certain anatomical challenges

Disadvantages:

- ↑Blood loss, ↑ post-op AKI or dialysis need
- Thromboemobolic events
- ↑Anhepatic/warm ischemia time
- Right phrenic nerve paresis r/t supra-hepatic caval clamp --> paradoxical hemidiaphragm, difficulty extubating

Veno-Veno Bypass (VVB)



(Deshpande & Chadha, 2018)

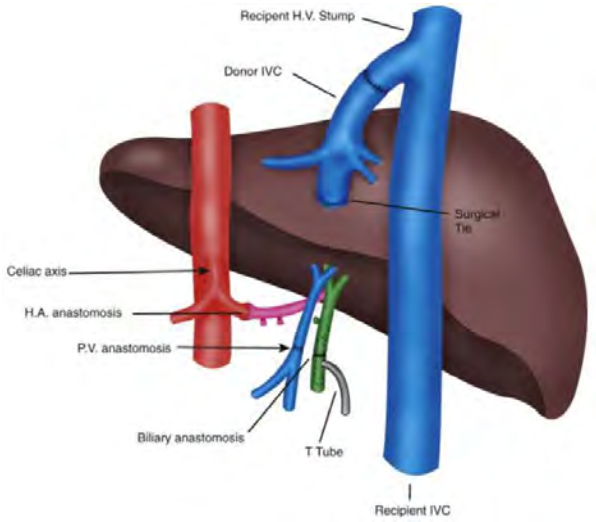
- FV & PV cannulated; blood pulled from systemic circulation
- Blood flows via heparin bonded tubing → centrifugal pump
- Blood returned to central circulation via axillary or IJ vein
- **Blood flow dependent on volume & pump flows**
- **Volume load prior to clamping** (hypovolemia/low flows→ obstruction)
- **Flows (~1.8-2L/min)** = maintains low/norm CO
- No systemic heparinization required

Advantages

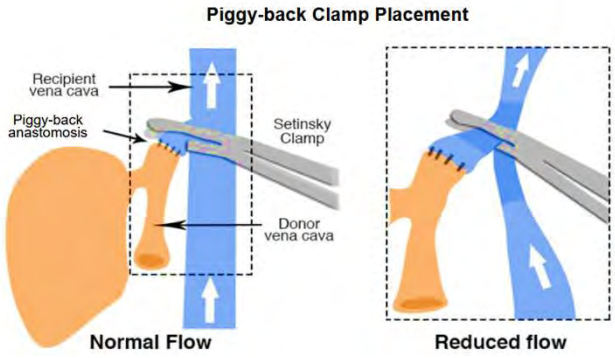
- Decompresses visceral organs, ↓ pulm edema
- Improved hemodynamics, renal & cerebral BF
- Dry surgical field

Disadvantages

- **Requires large bore return access, perfusionist may take IV access**
- ↑ Risk of VAE, thromboemboli, cerebral edema, hypothermia
- ↑ M&M, ↑ cost, No evidence of improved renal outcomes
- ↑ hemolysis, fibrinolysis & platelet activation
- **Activation of pro-inflammatory cytokines worsen postreperfusion**
- Contraindicated in highly thrombotic patients (Budd-Chiari, CA) → PE



(Drzezo, 2019)



(Deshpande & Chadha, 2018)

Piggyback Technique for OLT

- **Partial IVC flow maintained (25-50% in venous return)**
- Portal cross clamp → **20-30% loss of preload**
  - Less significant in cirrhotic pHTN with well-developed collaterals c/t ↓ MELDs
- Better for poor renal function
- Only an option for live-donor transplants

Advantages:

- Shorter, ↓ blood loss ↓ hemodynamic instability
- ↓ need for VVB

***Disadvantages*:**

- Space restrictions under diaphragm → injury ; ↓ IVC flow → thrombus
- ↓ portal drainage → congestion of intestines during PV clamping
- Mismatch in vessel sizes → converting to caval approach (13% cases)
- Piggyback syndrome: Intra-op/post-op venous outflow obstruction (1.5-8%; 40% → re-transplantation)

Anesthesia Preparation & Room Set-up

Vascular Access & Fluids

- Large bore IVs
- A line
- Double stick CVC:
  Cordis & AVA HF device to R IJ
- Swan Ganz catheter
- CCO machine
- PA/CVP transducers
- Rapid-infusion system
- Cell salvage?
- VVB/perfusionist
- CRRT with warmer
- Isotonic crystalloid (Plasmalyte) (3-4L)
- 5% Albumin (x10 bottles)

MTP preparedness:

- MELD>20: 20 RBC, 20 FFP platelet, cryo available

Equipment & Monitors

- Standard monitors
- BIS
- TEE
- Ultrasound
- Foley
- Core temp
- ICP monitor
- NGT?
- Video laryngoscope
- Multiple IV pumps
- Fluid warmers
- Bair huggers (upper, lower, underbody mat)
- ABG/ABE/iSTAT/co-oximetry
- TEG
- Defibrillator/pads
- Foam padding for PPs

Medications

- IV antibiotics (Zosyn q8)
- Steroid (solumedrol 500mg IV)
- Calcium (x10 syringes)
- Sodium Bicarb (x5-10 sticks)
- Insulin
- Dextrose
- Lasix, mannitol
- Methylene blue
- tPA, heparin

IV drips/emergency syringes:

- Phenylephrine (100mcg & 1mg/mL syringe*)
- Norepinephrine/ (8mcg/mL)
- Epinephrine/(10/100mcg/mL)
- Vasopressin/(0.4-1U/mL)
- Dopamine/dobutamine
- Nitroglycerin/(20mcg/ml)

Miscellaneous

- rFVIIa (rescue for uncontrollable bleeding)
- Blood bank runner
- ICU RN available for CRRT?
- 2:1 anesthesia provider to patient ratio

Patient Position:

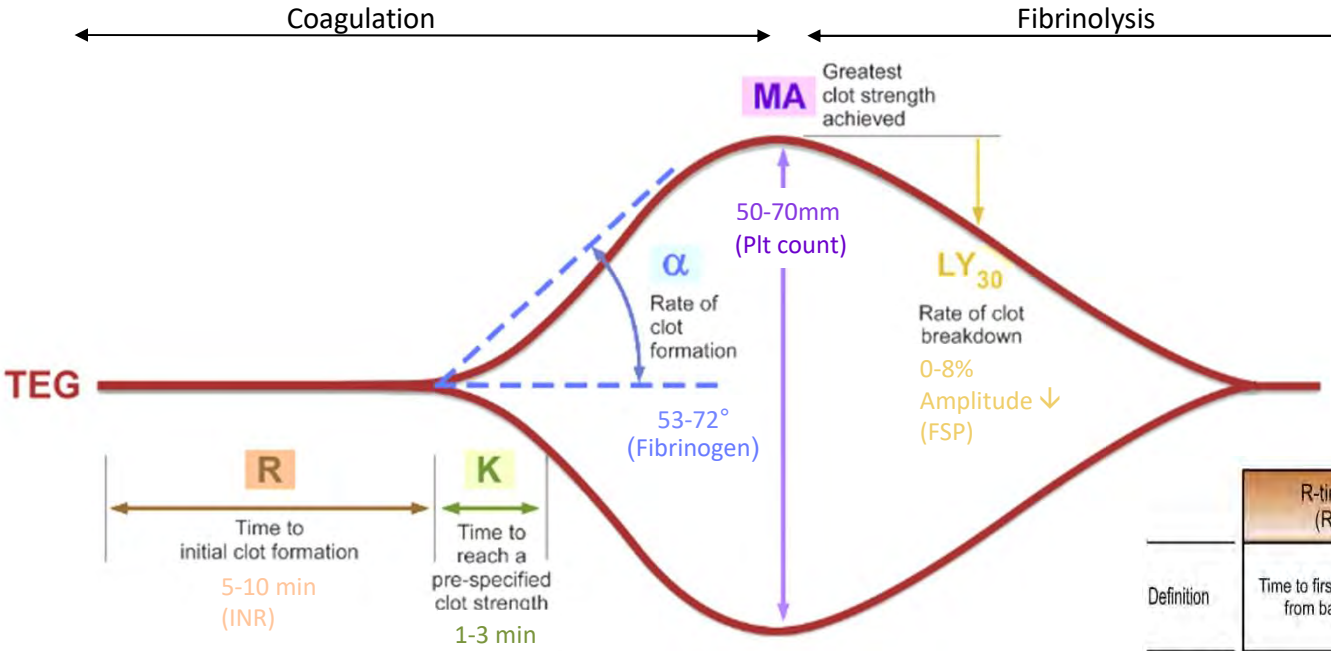
- Supine w/ L arm out
  R arm tucked &
  groin exposed for VVB
  Arterial line & PIV to Left
- OR
- Supine w/ both arms tucked

Cell Salvage with Cell Saver

- Intraoperative autotransfusion = safe & effective in OLT
- ↓allogenic transfusions
- For PRBC requirement >5 units
- Malignancy = relative contraindication
- Cell salvage suction device can be used after removal of ascites → up until point of biliary anastomosis
- Blood stored in reservoir, washed & filtered → debris, WBC, clotting factors & heparin removed
- ~50% of EBL recoverable
- RBCs suspended in NS → final Hct of 50%-80%
- 200 mL of cell-salvaged RBCs = 1 unit of PRBC
- EBL calculation =

  (cell saver return volume) x 3.4 (up to 4)

Thromboelastography (TEG)

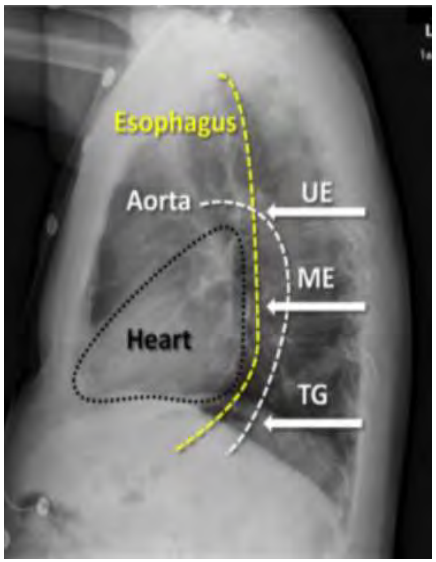


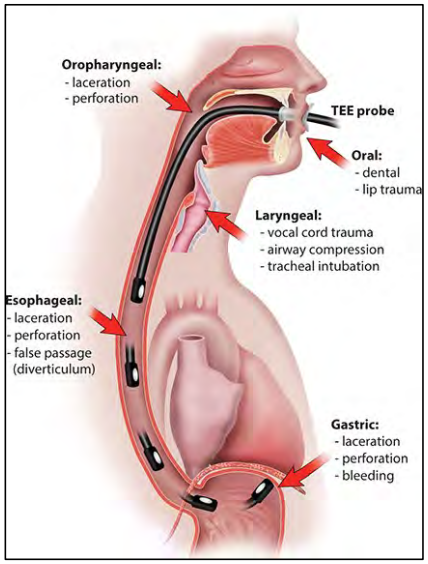
	R-time (R)	K-time (K)	Alpha angle (α)	Maximum Amplitude (MA)	Lysis % at 30 mins. (LY30)
Definition	Time to first deviation from baseline	Time for tracing to reach 20 mm amplitude	Angle between baseline and tangent line that intersects initial deviation	Maximum deviation of tracing from baseline	Decrease in curve amplitude (relative to MA) at 30 minutes
Controlling Pathways	Coagulation cascade	Fibrinogen cleavage Fibrin polymerization	Fibrinogen cleavage Fibrin polymerization	Fibrinogen activity Platelet count / quality	Fibrinolysis
Interpretation	⬆ = hypocoagulable ⇩ = hypercoagulable			⇩ = hypocoagulable ⬆ = hypercoagulable	
Therapeutic Implications	⬆ = administer fresh frozen plasma	If K time is ⬆ or alpha angle is ⇩, then: administer cryoprecipitate or fibrinogen concentrate		⇩ = administer platelets	⇩ = administer tranexamic acid

Sample Times:

- **Baseline**
- **Pre-anhepatic** (60min)
- **Early anhepatic** (5-10min)
- **Late anhepatic** (30-40min)
- **After Post-Reperfusion** (15min)
- **Neohepatic** (40min)

Transesophageal Echocardiography (TEE) for OLT





PROS of TEE (high benefit)

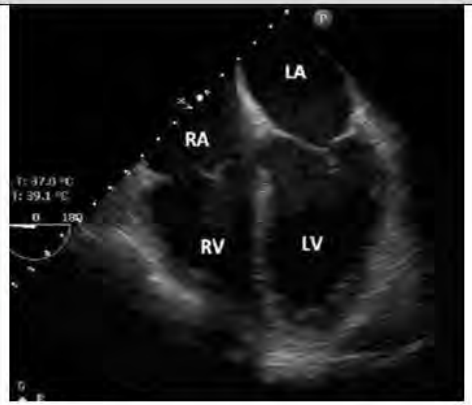
- Real-time, dynamic visualization of heart & pericardium
- Assesses volume status, contractility, wall motion
- Detects of thromboemboli & vascular wires
- Differentiates hemodynamic instability, guides treatment
- Detection of events that PAC cannot

CONS of TEE (low risk, <1%)

- Risk of bleeding & trauma/perforation
- Contraindications: large/untreated varices orrecent banding, UGIB, esophageal stricture,
- Limited # of trained providers; requires advanced knowledge & skill
- Cost & machine availability

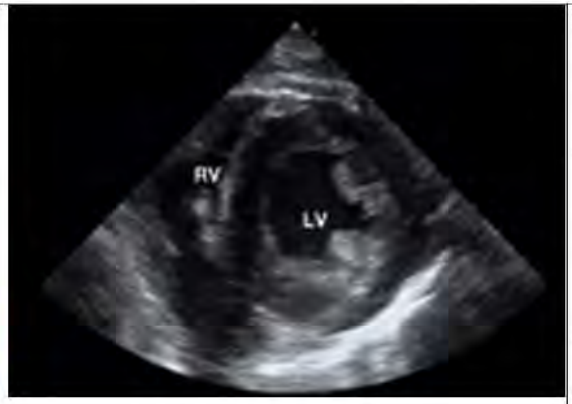
Monitoring Hemodynamics with Transesophageal Echocardiography (TEE) for OLT

- 4-5 focused views relevant to anesthesia providers
- Common causes of hypoTN during OLT diagnosed with TEE:
  - hypovolemia,
  - RV dysfunction,
  - LV dysfunction,
  - intracardiac thrombus (ICT)
  - pulmonary embolism (PE)
  - SAM/LVOTO
- TG Mid SAX view or ME 4C view ideal for monitoring ventricular function and volume status continuously during OLT

View Probe Depth Omniplane	Anatomical Reference	TEE Image	Common Findings per OLT surgical phase
Midesophageal 4-Chamber View (ME4C) 35-40cm 0°			***Most useful view throughout case & easiest to obtain*** • Visual of wires/PAC • LV/RV size & contractility • ~EF • RWMA • Volume status Differentiates instability (↓volume vs. ↓contracility) • Pericardial effusion & tamponade • Intracardiac clot/PE/micro-emboli

Monitoring Hemodynamics with Transesophageal Echocardiography (TEE) for OLT

- Abnormal findings very common (between 41-88%)
- Focused TEE protocols captured 92% of common TEE diagnoses in OLT identified → 94% resulted in intraoperative management changes
- greatest # of abnormal findings seen in reperfusion phase
  - Most common = RV dysfunction, thromboemboli, and biventricular dysfunction

Trangastric Short Axis @ Papillary Muscles (TG SAX PAP) 40-45cm 0°		 RV, LV, IVS, papillary muscles	• Differentiates instability (↓volume vs. ↓contracility) • loss of LV preload → approximation of papillary muscles (↓ LV diameter/"kissing papillary sign") • ventricular fx assessment • RV failure = IVS bowing • RWMA (all 3 coronary perfusing regions visualized

Targets for Replacement Therapy: Maintaining Hemostasis

Maintain hemostasis → optimize clot formation

- Temp > 35°C, pH >7.2, BE < -3, lactate < 2
- K < 4, Ca > 1

Crystalloids

- Balanced soln, Plasmalyte (PL) preferred
- Limit use (~5L/case)

Colloids

- Albumin: 5% ↓ overall fluid/pulm edema
- Albumin 20% ↓ risk of hypervolemia (anhepatic)

Blood Products

- Continuous factor replacement
- Slight preference of FFP > PRBC & crystalloid
- Ratio PRBC: FFP: PL = 200:300:250mL = Hct 26–28% / coags 30–50 % norm

Transfusion Triggers

PRBC

- Hgb ≥7 / Hct 26- 30%

FFP

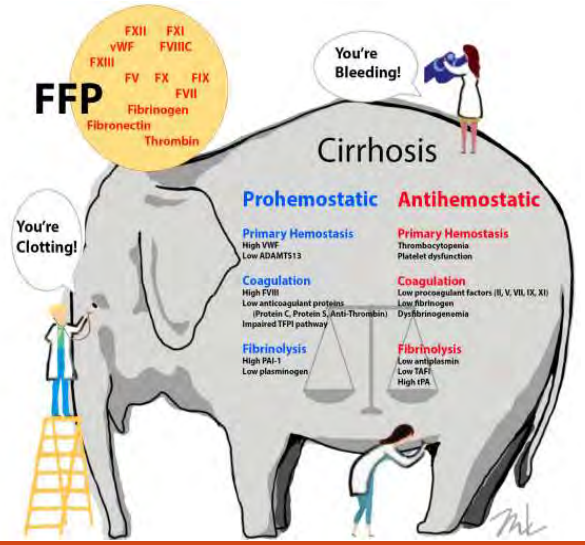
- INR < 1.5-2.0, R > 10-14'
- > 15' → 2 units

Platelets

- < 50,000, MA <40-55mm

Cryoprecipitate

- Fg < 80-100, α-angle <40-45°



Anesthesia Induction & Maintenance

Induction

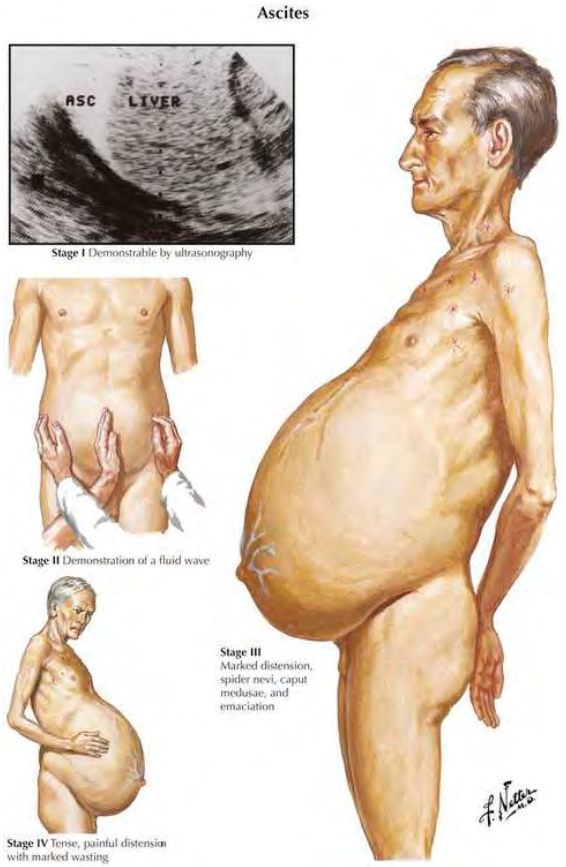
- Pre-op Aline generally not required…
- Propofol or etomidate = preferred; lower doses
- Remimazolam: rapid metabolism & stable hemodynamic profile
- Cisatracurium vs. Rocuronium

Intubation

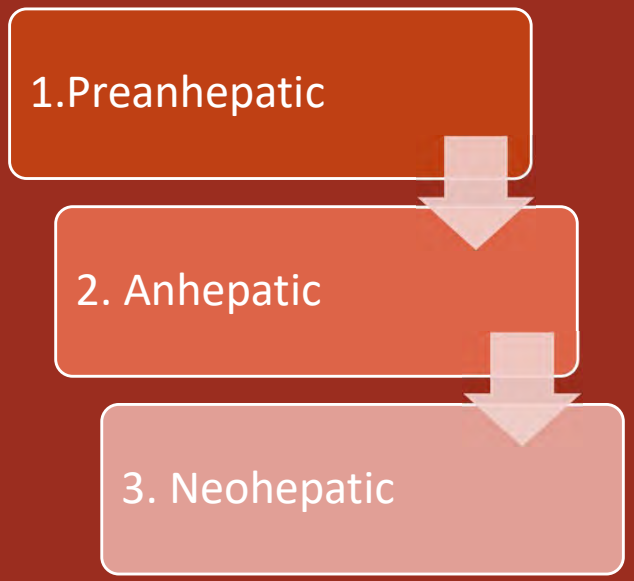
- ↓ Lung & chest wall compliance, unable to lay supine
- ↓ FRC /↑ Risk of Hypoxia
- Full stomach/risk of aspiration
- ↑ Risk of Bleeding

Maintenance of Anesthesia

- Routine maintenance
- ↓ MAC requirements (sub-therapeutic [MAC]
- MAC & MELD have inverse relationship



Overview: Phases of OLT



Preanhepatic/Dissection phase — **Cold Ischemia**

- **Incision to (just before) cross-clamping** of hepatic artery (HA) & portal vein (PV)
- Native liver is dissected, structures identified, liver mobilized

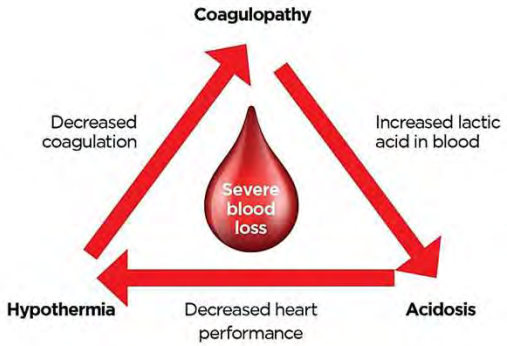
Anhepatic phase — **Warm Ischemia**

- **Begins with cross-clamping** vascular inflow to the liver (HA, PV) (functionally anhepatic)
- Removal of native, diseased liver (patient now **anhepatic**)
- **Re-anastomosis** of transplanted liver graft

Neohepatic phase — **Reperfusion**

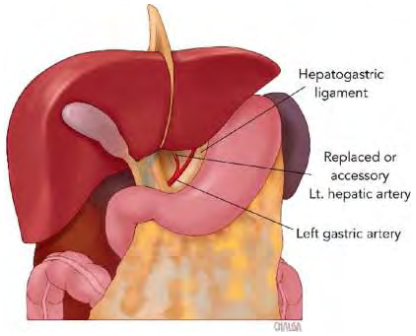
- Removal of clamps & **reperfusion** of liver allograft
- Restoration of hemostasis & reconstruction of vessels
- Biliary anastomosis
- Abdominal closure

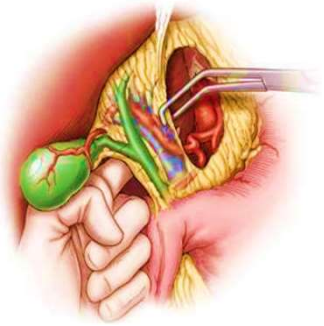
Pre-Anhepatic/Dissection Phase



Surgical Details

- Donor liver preserved post-procurement in cold, acidotic, hyperkalemic, anoxic solution
- B/L subcostal incisions with midline extension ("Mercedes incision")
- Ascites drainage
- Mobilization of liver & perihepatic structures
- Adhesions & collaterals → **extensive surgical bleeding**





Major Anesthetic Issues

- Hemorrhage**/hypovolemia
- Coagulopathy
- Hypothermia
- Electrolyte abnormalities & acid/base disturbances
- *Preparation* for vascular clamping

Anesthetic Techniques

- Maintain normovolemia with careful balance of vasoactive agents to maintain perfusion & ↓ blood loss
- Incorporate positive inotropic agents to augment HR & ↑ CO
- Maintain normothermia
- Transfusion (possibly MTP)

Pre-anhepatic

"Low CVP"?

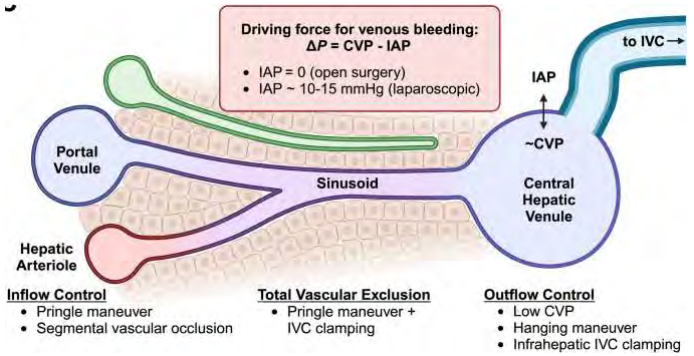
- CVP indirectly reflects hepatic venous pressure
- Low CVP = ↓ resistance to venous outflow = ↓ liver back bleeding
- **pre-anhepatic phase CVP ≤5** recommended to **↓ blood loss**
- **High CVP = hypervolemia, large ascites, pleural/pericardial effusion**
- Most data from non-transplant surgery, controversial in OLT due to ↑ vulnerability to renal failure in ESLD
- **Lack of evidence to show benefits outweigh risks in OLT**

Advantages

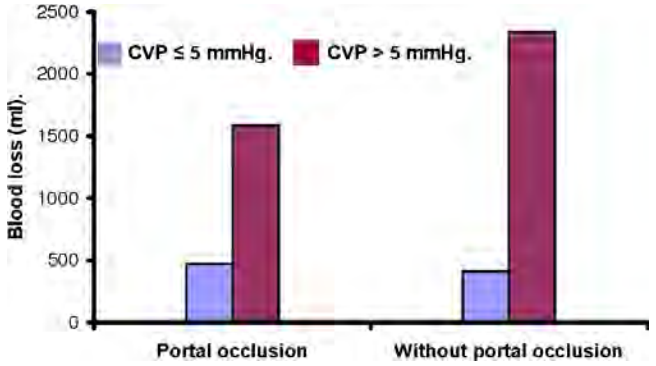
- ↓ blood loss
- ↓ transfusion volume
- ↓ transfusion related acute lung injury

Disadvantages

- ↑ risk of hypotension, tissue hypoperfusion & lactic acidosis; ↑ vasopressor requirements
- ↑ risk of AKI, renal failure/post-op dialysis
- ↑ risk entrainment of air emboli
- ↑risk of M&M



(Marcus, et al., 2024)

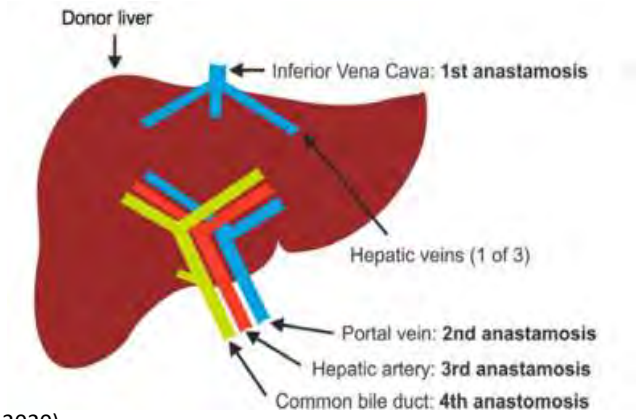


(Eid, et al., 2005)

Anhepatic Phase

Surgical Details

- Recipient liver removed from field
- Donor liver flushed with 1-2L cold albumin before insertion
- Caval & portal anastomoses completed
  - Caval = suprahepatic IVC, infrahepatic IVC, portal vein
  - Piggyback = suprahepatic, portal vein
- Surgeon back bleed ~300-500mL flush preservatives & air
- Surgeons give 10-minute reperfusion warning



(Millson, et al., 2020)

Major Anesthetic Issues

- Correct acid/base disturbances (rapid acidosis, ↓Ca++, ↑K+, worsening coagulopathy)
- Relative hypo/normovolemia
- Bleeding

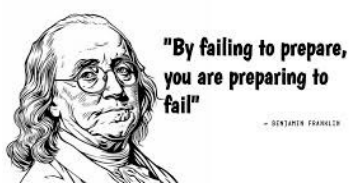
Anesthetic Management

- Administer immunosuppression at clamping
- Minimal volume resuscitation to avoid gross hypervolemia & graft congestion upon reperfusion
- Avoid platelet/cryo infusions, NO antifibrinolytics/protamine during anastomoses
- Maintain normothermia

PREPARE FOR REPERFUSION

- Proactive augmentation of hemodynamics, electrolytes and pH to sustain massive drop during immediate reperfusion period

Anhepatic Phase



ANTICPATE reperfusion related effects

- Organ preservation fluid washed out of graft → systemic circulation
- U. of Wisconsin Soln. = high K+ load (120mEql/L)
- Cold, ischemic, acidotic blood with high-potassium load returning with possible air, clots → heart very suddenly upon clamp release. You should expect:
- Hyperkalemia → arrest
- Bradycardia, AV blocks (5%) → asystole (30%)
- Severe hypotension, acidosis & ↓ vasopressor sensitivity
- Acute right sided heart failure, pulm edema
- Emboli (air, clots) → intracardiac or PE

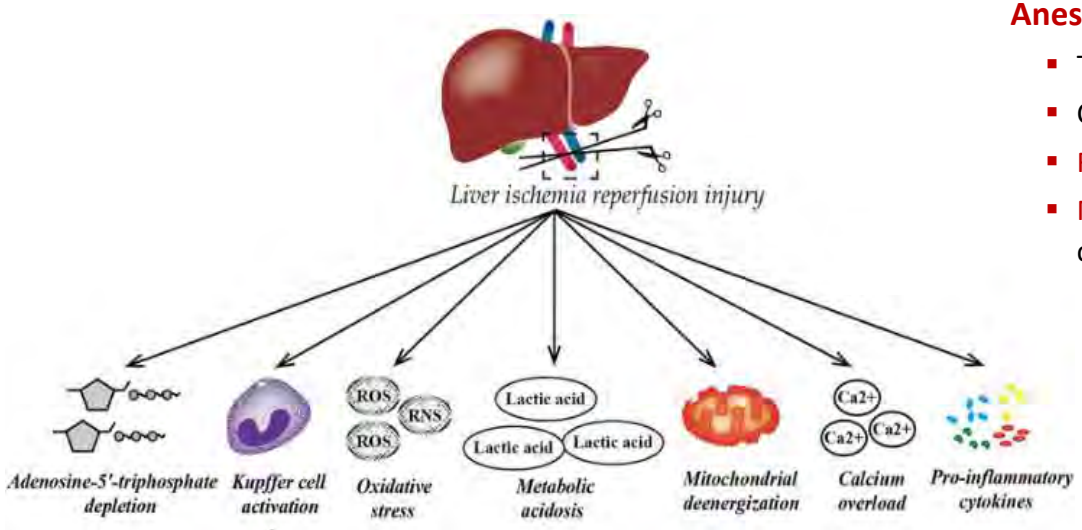
PREPARE for reperfusion

- ↑ BP / ↑ HR (SBP ~150-160, HR ~100)
- Augment to tolerate acute 30% ↓ in BP & HR, prioritize inotropes
- Start epinephrine gtt 10-15' prior to reperfusion (2-5mcg/min)
- Hematocrit 25-35%: ↓ blood viscosity in Low flow state
- ↓K^+ to <3.5mEq/L: Hyperventilation, insulin/glucose, CA^{++},albuterol, double wash blood products
- Ca^{++}: 1-2g to stabilize membrane
- ↑pH (BE to 0): bicarb gtt/THAM
- FiO2 100%, volatile gas decreased

Neohepatic Phase: Portal Reperfusion

Surgical Details

- Prior to reperfusion, IVC unclamped, restoring preload to heart
- Vascular unclamping releases obstructed BF from portal circulation
- **1st clamp released = Portal Vein = "Portal Reperfusion",** or simply **"Reperfusion"**



Major Anesthetic Issues

- **0-5min after unclamping = most critical, severe instability**
- Cold, metabolic & vasodilatory inflammatory byproducts → RA & PA
- Profound ↓ contractility, HR & SVR → ↓ RV preload, ↓R coronary perfusion
- Acidosis/hypercarbia/hypothermia/hypoxia → PA vasoconstriction → Right HF
- Post-Reperfusion Syndrome (PRS) & Ischemia Reperfusion Injury (IR)

Anesthetic Management

- Tx with inotropic boluses (epi 10-100mcg), calcium, bicarb
- Cardiac pacing, defibrillation, cardiac massage
- Refractory vasoplegia → methylene blue (2mg/kg)
- Monitor TEE for evidence of emboli TEE → heparin 3000-5000 unit to prevent clot expansion, PE → low dose tPa 0.5-4mg

(Mao, et al, 2022)

Post-Reperfusion Syndrome

Incidence

- ~25-30%, >40% for acute hepatic failure

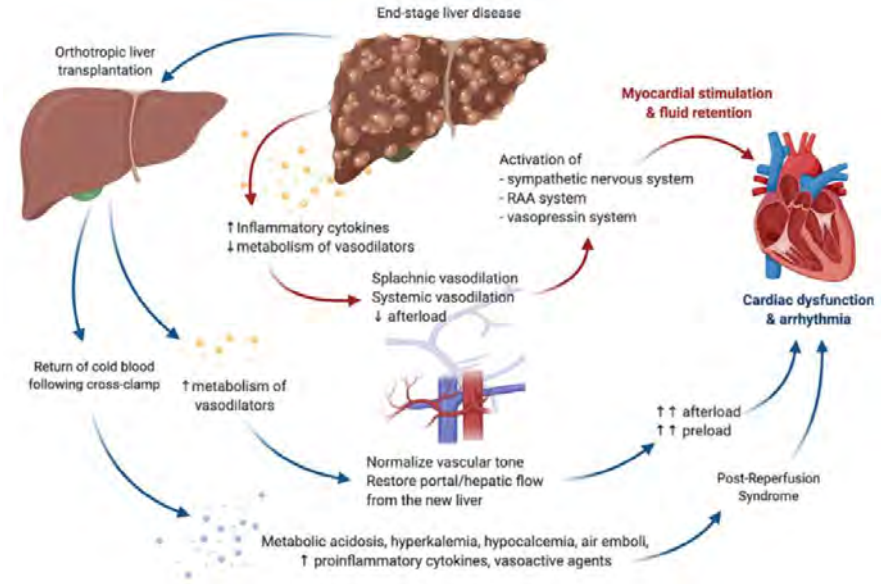
PRS correlated with

- ↑ in-hospital mortality
- ↓ survival rates at 15 days, 3, 6, 12 months
- ↑ post-op AKI, early allograft dysfunction,

PRS Risk Factors

- Advanced age (donor & recip. age >55-60)
- DCD grafts
- ↑ cold ischemic time*
  w/o hypothermic mechanical perfusion
- ↑ MELD, creatinine
- Hyponatremia (< 130 mmol/l), Hyperkalemia, Hypothermia
- Renal failure
- Left ventricular diastolic dysfunction
- Conventional technique vs piggyback
- Volume of transfused blood components
- Increased calcium requirement during surgery
- reperfusion without flushing vena cava

- Sustained ↓ MAP greater than 30% below the baseline value >1 min during first 5 minutes after reperfusion (usually resolves in <15 min)



Rhee, et al. 2022

Neohepatic Phase: Post-reperfusion

Surgical Details

- hepatic artery reconstruction/anastomosis to optimize oxygenated BF to new graft
- **2nd vascular clamped released = Hepatic Artery → "Hepatic Reperfusion"**
- Surgical hemostasis obtained
- If unstable/bowel swelling → delay bile duct & closure
- If patient stable & hemostasis achieved → cholecystectomy & bile duct anastomosis
- Bile production = strong indication of graft function

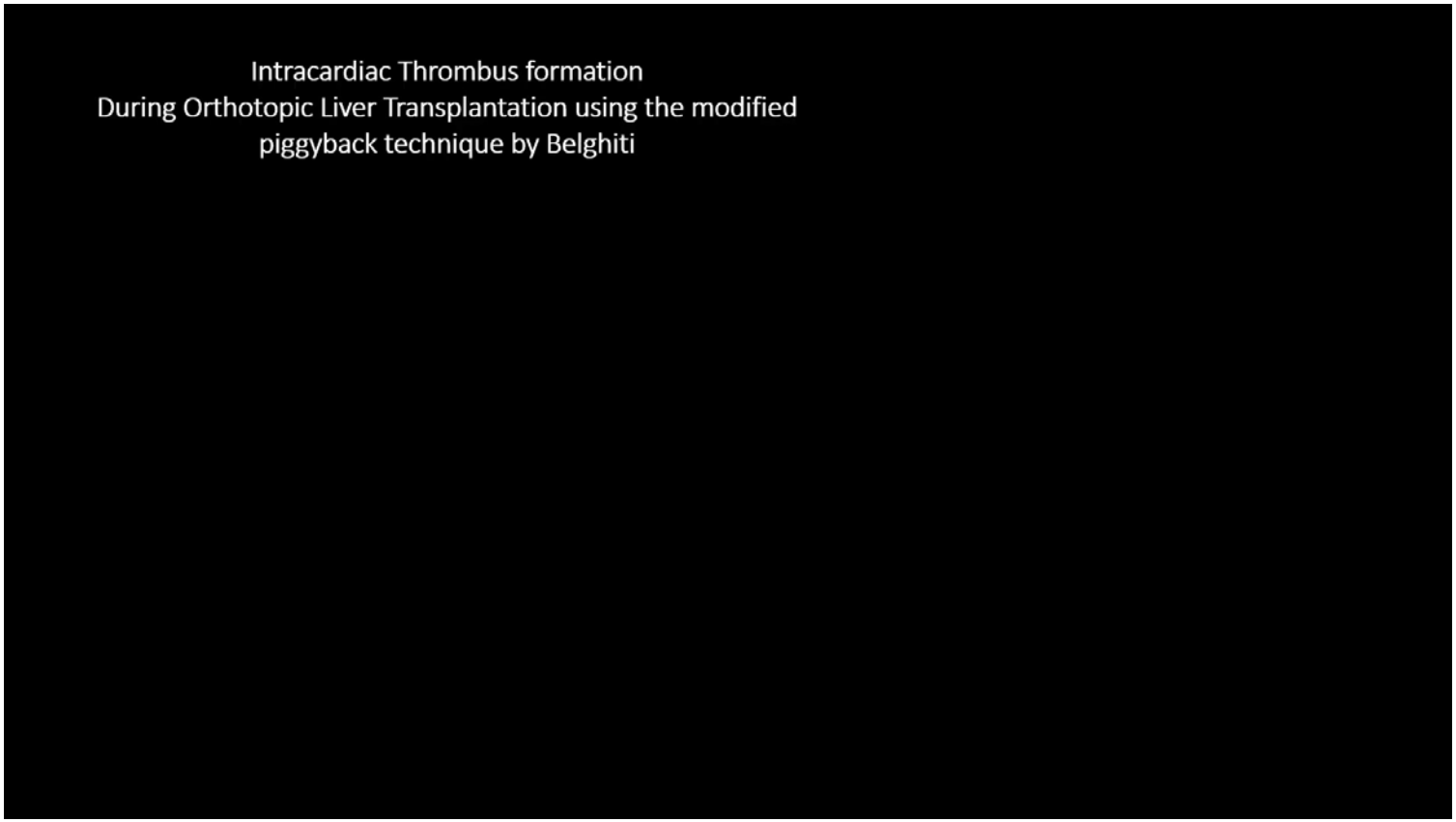
Major Anesthetic Issues

- Coagulopathy/Bleeding
- Less profound hemodynamic shifts
- Hypervolemia
- Extubation/"Fast Track"?

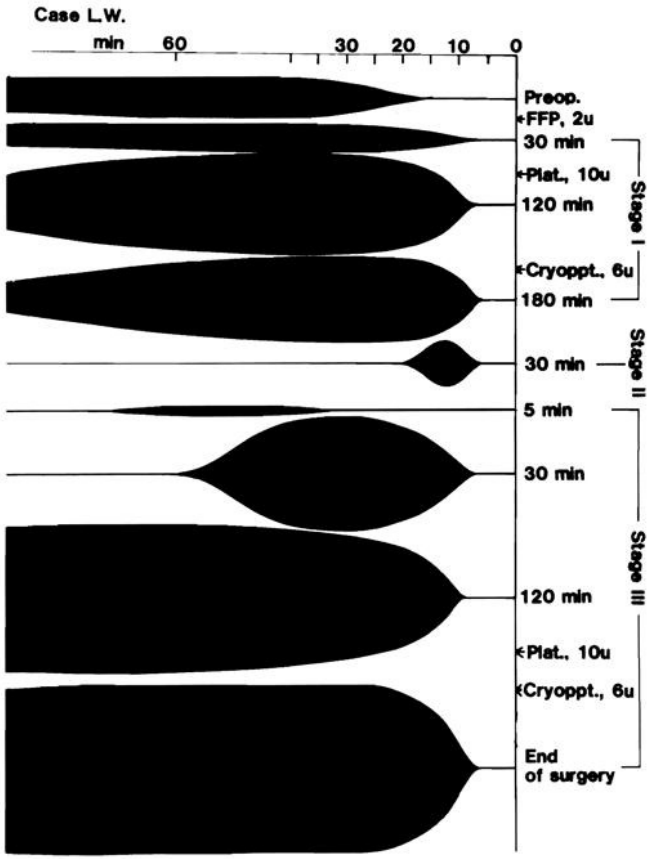
Anesthetic Management

- Lab/TEG & evidence of bleeding guides blood transfusion
- Caution with platelets/cryo; **avoid hypercoagulable states**
- PAP > 30 mmHg & CVP > 15 mmHg → HOB elevated, diuresis and/or nitro
- Carefully place OGT to decompress for closure
- ↓ vasopressor/inotropic support
- Communicate inability to wean vasopressors (possible graft dysfunction)

Intracardiac Thrombus at Reperfusion



Vetrugno, et al., 2021



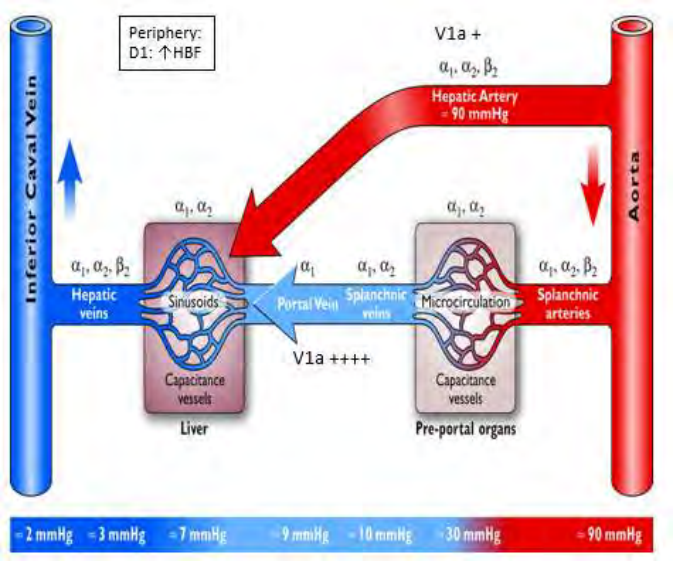
(Kang, et al., 1985).

Coagulopathies by Stage

Stage	Coagulation abnormalities increasing bleeding	Other risk factors for bleeding	TEG
Dissection	Thrombocytopaenia Platelet function defects Increased nitric oxide and prostacyclin Low levels of factors II, V, VII, IX, X, XI Vitamin K deficiency Low levels of alpha 2 anti-plasmin, factor XIII, thrombin activatable fibrinolysis inhibitor Elevated t-PA Dysfibrinogenaemia	Surgical technical difficulty Portal hypertension Oesophago-gastric venous distension secondary to compression and vascular clamping	Prolonged R time Decreased alpha-angle Reduced MA
Anhepatic	Reduced coagulation factor synthesis Reduced clearance of t-PA	Duration greater than 45 min	Increased lysis
Reperfusion	"Heparin like effect" Platelet entrapment in sinusoids of donor liver Reduction of all coagulation factors Decreased PAI-1 Decreased antifibrinolytic factors Hyper-fibrinolysis	Acidosis Hypothermia	Virtually "flat" native trace with prolonged R time and significantly reduced MA Heparinase trace required Lysis
Post reperfusion	Accelerated t-PA release Thrombocytopaenia (balanced by increased activation)	Delayed graft function	MA reduced

(Clevenger & Mallet, 2014)

Maintaining Hemodynamic Stability with Vasoactive Agents



Phenylephrine (pure α-agonist)

- ↑SVR, ↓CO/CI, ↑ CVP, ↓Portal BF
  - ↓ **bleeding during dissection phase**; must correct hypovolemia
  - ↑ afterload may **unmask cardiomyopathy** (do not use for SVR>1200dynesxs/cm5)
  - Pretreatment bolus prior to reperfusion to↓ **PRS at reperfusion**

Norepinephrine (α1 > β1)

- Vasoconstricts sinusoids→ ↓ hepatic BF/volume, ↑portal HTN; ↑SVR, ↑CO/CI
- ↑ doses → severe peripheral vasospasm → **lactic acidosis**

Epinephrine (α1 > β1 > β2, dose dependent)

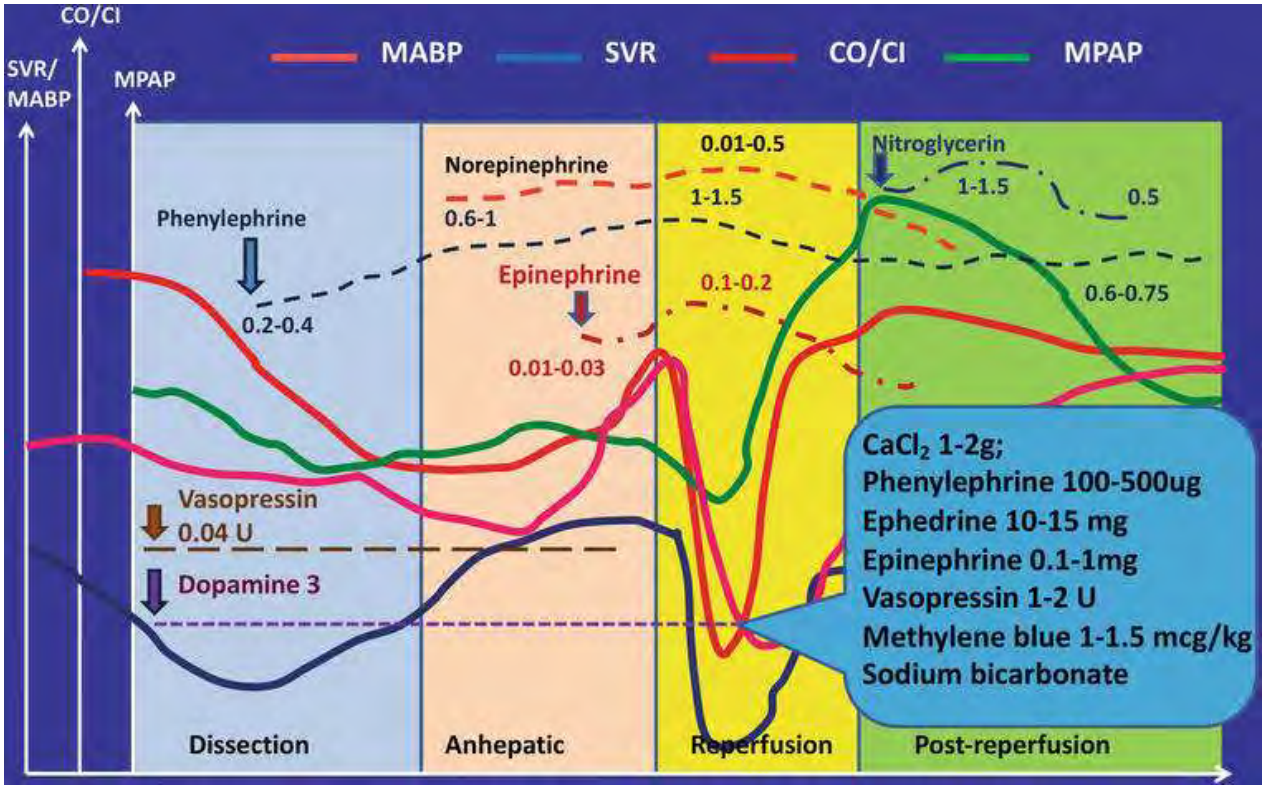
- ↑CO/CI, ↓SVR (@ lower doses), vasoconstricts sinusoids→ ↓ hepatic BF/volume, ↑portal HTN
- Dysthymias; ↓ liver/kidney perfusion → lactic acidosis; dose dependent ↓hepatic circulation
- Pretreatment bolus prior to reperfusion to↓ **PRS at reperfusion**

Vasopressin (V1a)

- ↑SVR, ↑CO/CI, ↓MPAP, ↓ CVP, ↓ PP/portal BF, ↓HBF, ↑ renal fx/diuresis, ↑VWBF, 0 lactic acidosis, ↑platelet aggregation (thrombotic risk?)
- **ESLD have endogenous vasopressin deficiency & reacting very briskly & dramatically**
- **Norepinephrine sparing** effect with simultaneous infusions
- **Selectively constricts splanchnic vessels**
- ↓ **blood loss (**dissection & anhepatic phases); **may impair portal blood flow to allograft** post-reperfusion (neohepatic phase: keep <5 unit/hr and titrate to low dose < 3unit/hr)

Dopamine (β1 > D1 > α1 @ <5mcg/kg/min)

- Low/mod (3mcg/kg/min) → ↑renal BF/GFR, ↑HR, ↑CO/CI
- Risk of tachycardia & dysrhythmias



(Vitin, et al, 2017)

Maintaining Hemodynamic Stability with Vasoactive Agents

Pre-Anhepatic phase

Goals:

- ↓ portal BF to ↓ bleeding = vaso and/or neo gtt
- ↓ portal BF & ↑CO early low dose levo (w/ β1 stim)
- ↑renal BF, ↑CO = dopamine (renal dose)

Anhepatic phase

Goals: augment BP/HR by 30% to

- ↑ ↑ CO /start to ↑ HR= add epi; titrate ↑↑ prior to reperfusion for more inotropy & chronotropy
- ↑ SVR/CO: levo, titrate ↑ prior to reperfusion
- ↑ SVR/CO: can titrate vaso, stay < 5 unit/hr

Pre-emptive boluses before reperfusion

- CaCl 1-2g: membrane stabilization
- Bicarb 1-2 amps
- Epi 0.1-0.5mg
- Ephedrine 10-15mg: ↓ incidence/severity of PRS
- Phenylephrine 100-500mcg: ↓ incidence/severity of PRS

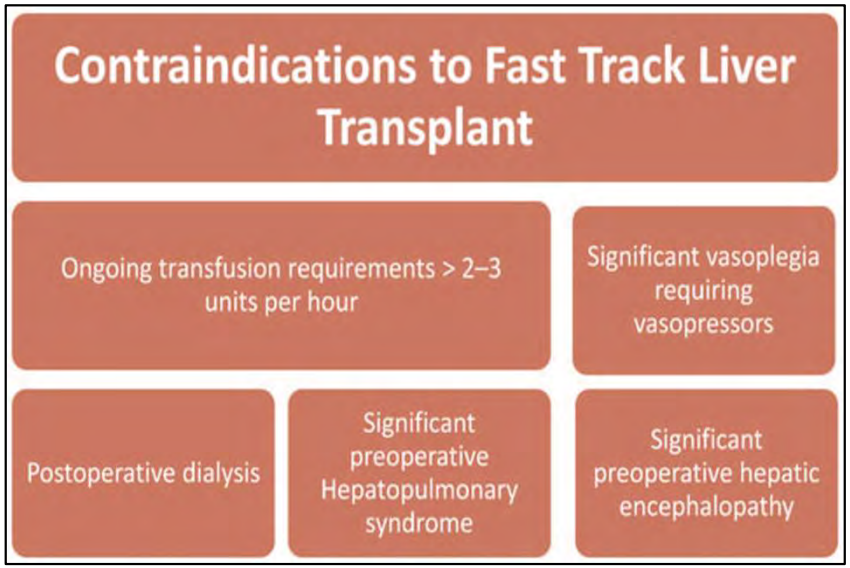
Neohepatic

Goals:

- ↑ Portal/hepatic artery BF for graft perfusion; ↑ hepatic vein BF for venous drainage: titrate pressors (epi → dopa → vaso/ levo)
- ↓ graft congestion→ ↓ CVP/MPAP: nitro gtt, diuresis

“Fast Track” Extubation

- No universally adopted standard
- Communicate with surgical team
- Consider
  - Age, BMI, MELD, graft status
  - Duration of the surgery
  - Amount of blood transfused
  - current vasopressors
- Benefits:
  - ↑ early graft function
  - ↓ ICU length of stay
  - ↓ nosocomial infections
  - ↓ costs



Conclusion

- Anesthesia for liver transplants is complex, challenging, dynamic & rewarding
- Complexities best managed by dedicated anesthetic team
- Effective communication with patients, surgeons, multidisciplinary team is paramount
- Continued research, advanced training, clinical experience, & collaboration key in improving patient survival in OR and long-term
- *Consider becoming an organ donor!*


Thank you!

References

Abdominal Key (2017, August 23). Orthotopic liver transplantation: Surgical techniques [picture of caval technique clamping]. Retrieved from https://abdominalkey.com/orthotopic-liver-transplantation-surgical-techniques/

American Gastroenterological Association. (2020, May 26). New AGA guidance addresses cancer screening in NAFLD patients *[Online image]*. https://gastro.org/news/new-aga-guidance-addresses-cancer-screening-in-nafld-patients/

Ander, M. Mugve, N. Crouch, C., Kassel, C., Fukazawa, K, Isaak, R., Deshpande, R., McLendon, C., & Huang, J. (2024). Regional anesthesia for transplantation surgery – A White Paper part 2: Abdominal transplantation surgery. Clinical Transplantation, 38(1). https://doi.org/10.1111/ctr.15227

Aneja, S. & Malik, A. (2023). Intraoperative complications and management. In In V. Vohra, N. Gupta, A. S. Jolly, & S. Bhalotra (Eds.), Peri-operative anesthetic management in liver transplantation. Springer: Singapore. https://doi.org/10.1007/978-981-19-6045-1_18

Aniskevich, S., Scott, C. L., & Ladlie, B. L. (2023). The Practice of Fast-Track Liver Transplant Anesthesia. *Journal of Clinical Medicine*, *12*(10), 3531. https://doi.org/10.3390/jcm12103531

Arcas-Bellas, J. J., Siljeström, R., Sánchez, C., González, A., & García-Fernández, J. (2024). Use of transesophageal echocardiography during orthotopic liver transplantation: Simplifying the rocedure. *Transplantation direct*, *10*(2), e1564. https://doi.org/10.1097/TXD.0000000000001564

Arora, H. & Kumar, P. (2020). Time to simplify transesophageal echocardiography for liver transplantation? *Journal of Cardiothoracic and Valvular Anesthesia, 34,* 1833-1835. https://doi.org/10.1053/j.jvca.2020.03.019

Bowen, A. D., Keslar, P. J., Newman, B., & Hashida, Y. (1990). Adrenal hemorrhage after liver transplantation. *Radiology*, *176*(1), 85–88. https://doi.org/10.1148/radiology.176.1.2191375

Bulatao, I.G., Heckman, M.G., Rawal, B., Aniskevich, S., Shine, T.S., Keaveny, A.P., Perry, D.K., Canabal, J., Willingham, D.L., & Taner, C. B. (2014). Avoiding stay in the intensive care unit after liver transplantation: a score to assign location of care. *American journal of transplantation :Official journal of the American Society of Transplantation and the American Society of Transplant Surgeons*, *14*(9), 2088–2096. https://doi.org/10.1111/ajt.12796

Butterworth, J. F., Mackey, D. C., & Wasnick, J. D. (Eds.). (2013). *Morgan & Mikhail's clinical anesthesiology* (5th ed.). McGraw-Hill Education.

Brezeanu, L.N., Brezeanu, R.C., Diculescu, M., & Droc, G. (2020). Anaesthesia for liver transplantation: An update. *Journal of Critical Care Medicine (Universitatea de Medicina si Farmacie din Targu-Mures), 6*(2), 91–100. https://doi.org/10.2478/jccm-2020-0011

Cekman, N. & Uslu, A. (2024). Intraoperative cardiac complications in liver transplantation: Preoperative evaluation – A narrative review. *Indian Journal of Transplantation, 18*(4) 360-366. doi: 10.4103/ijot.ijot_52_24

Chen, Z., Ju, W., Chen. C., Wang, T., Yu, J., Hong, X., Dong, Y., Chen, M., & He, X. (2021). Application of various surgical techniques in liver transplantation: A retrospective study. Annals of Translational Medicine, 9(17). doi: 10.21037/atm-21-1945

Clevenger B, Mallett S.V. (2014). Transfusion and coagulation management in liver transplantation. *World Journal of Gastroenterology, 20*(20): doi: 10.3748/wjg.v20.i20.6146]

Cutler, J. (2023, August 2). Hepatic blood supply and regulation of hepatic blood flow. Open Anesthesia. https://www.openanesthesia.org/keywords/hepatic-blood-supply-and-regulation-of-hepatic-blood-flow/?search_term=hepatic%20blood%20supply

De Pietri L., Mocchegiani, F., Leuzzi, C., Montalti, R., Vivarelli, M., & Agnoletti, V. (2015). Transoesophageal echocardiography during liver transplantation. World Journal of Hepatology, 7(23): 2432-2448. doi: 10.4254/wjh.v7.i23.2432]

Deshpande, R. & Chadha, R.M. (2018). *Anaesthesia tutorial of the week: Anaesthesia for Orthotopic Liver Transplantation*. In Doane, M.A. & Poon, C. (Eds.), World Federation of Societies of Anaesthesiologists (WFSA). https://resources.wfsahq.org/wp-content/uploads/377_english.pdf

Drzezo. (2019, June 23). Liver transplantation imaging [Image: surgical anatomy of OLT by piggyback IVC anastomotic technique]. Radiology Key. https://radiologykey.com/liver-transplantation-imaging-2/

Di Lullo, L., Bellasi, A., & Cozzolino, M. (2017). Pathophysiology of the cardiorenal syndromes types 1–5: An uptodate. *Indian Heart Journal, 69*(2), 255–265. https://doi.org/10.1016/j.ihj.2017.01.005

Drummond, J.C. & Petrovitch, C.T. (2005). Intraoperative blood salvage: Fluid replacement calculations. International Anesthesia Research Society, 100, 645-659. doi: 10.1213/01.ANE.0000144069.36647.3D

Eid, E.A., Sheta, S.A., & Mansour, E.E. (2005). Low central venous pressure anesthesia in major hepatic resection. *Middle East Journal of Anaesthesiology, 18*(2), 367-77.

European Association for the Study of the Liver (EASL) (2015). Clinical Practice Guidelines: Liver transplantation. *Journal of Hepatology, 64*(2), 433-485. doi: 10.1016/j.jhep.2015.10.006

Farkas, J. (2019, June 17). PulmCrit-TEG for cirrhotic coagulopathy: Time for clinical implementation? EmCrit. https://emcrit.org/pulmcrit/teg-cirrhosis/

Flood, P., Rathmell, J. P., & Shafer, S. (2015). *Stoelting's pharmacology and physiology in anesthetic practice* (5th ed.). Wolters Kluwer Health.

Fitzsimons, M., Dalia, A.A., Essandoh, M., Black, S.M., Schenk, A.D, Stein, E., Turner, K., Sawyer, T.R., Iyer, M.H. (2023). Intracardiac thrombosis and pulmonary thromboembolism during liver transplantation: A systematic review and meta-analysis. *American Journal of Transplantation, (23)*8, 1227-1240. doi: 10.1016/j.ajt.2023.04.029

Fukazawa, K. & Pretto, E.A. (2012). The post-reperfusion syndrome (PRS): Diagnosis, incidence and management. In *Tech. https://www.intechopen.com/chapters/28628*

Gao, Q., Cai, J. Z., & Dong, H. (2024). A review of the risk factors and approaches to prevention of post-reperfusion syndrome during liver ransplantation. *Organogenesis*, *20*(1). https://doi.org/10.1080/15476278.2024.2386730

Gaspari, R., Teofili, L., Aceto, P., Valentini, C. G., Punzo, G., Sollazzi, L., Agnes, S., & Avolio, A. W. (2021). Thromboelastography does not reduce transfusion requirements in liver transplantation: A propensity score-matched study. *Journal of Clinical Anesthesia, 69.* https://doi.org/10.1016/j.jclinane.2020.110154

Gelman, S., & Mushlin, P. S. (2004). Catecholamine-induced changes in the splanchnic circulation affecting systemic hemodynamics. *Anesthesiology, 100,* 434–439.

Groose,M.K., Aldred, B.N., Mezrich, J., Hammel, L. (2019). Risk factors for intracardiac thrombus during liver transplantation. *Liver Transplantation, 25*(11), 1682-1689. doi: 10.1002/lt.25498

Henriksen, J. H., & Møller, S. (2009). Cardiac and systemic haemodynamic complications of liver cirrhosis. *Scandinavian Cardiovascular Journal, 43*(4), 218–225. https://doi.org/10.1080/14017430802691528

Hilmi, I., Horton, C.N., Planinsic, R.M., Sakai, T., Nicolau-Raducu, R., Damian, D. Gligor, S., Marcos, A. (2008). The impact of postreperfusion syndrome on short-term patient and liver allograft outcome in patients undergoing orthotopic liver transplantation. *Liver Transplantation, 14*, 504-508.

Hines, R. L., & Marschall, K. (Eds.). (2018). *Stoelting's anesthesia and co-existing disease* (7th ed.). Elsevier.

Hofer, R.E., Vogt, M.N.P.; Taner, T., Findlay, J.Y. (2020). Influence of intraoperative transesophageal echocardiography and pulmonary artery catheter monitoring on outcomes in liver transplantation. *Transplantation Direct 6*(2). doi: 10.1097/TXD.0000000000000972

Intagliata, N. M., Davitkov, P., Allen, A., Falck-Ytter, Y. T., & Stine, J. G. (2021). AGA technical review on coagulation in cirrhosis [Image of hemostasis]. *Gastroenterology, 161*(5), 1630–1656. https://doi.org/10.1053/j.gastro.2021.09.004

Jaffe, R. A., Samuels, S. I., Schmiesing, C. A., & Golianu, B. (Eds.). (2009). *Anesthesiologist's manual of surgical procedures* (5th ed.). Lippincott Williams & Wilkins.

Kang, Y., Elia, E. (2017). Anesthesia Management of Liver Transplantation. In: Doria, C. (eds) Contemporary Liver Transplantation. Organ and Tissue Transplantation. Springer, Cham. https://doi.org/10.1007/978-3-319-07209-8_9Kashimutt, S. & Kotzé, A. (2017). Anaesthesia for liver transplantation. BJA Education, 17(1), 35–40, https://doi.org/10.1093/bjaed/mkw031

Kang, Y.G., Martin, D.J., Marquez, J., Lewis, J.H., Bontempo, F.A., Shaw, B.W., Jr, Starzl, T.E., & Winter, P.M. (1985). Intraoperative changes in blood coagulation and thrombelastographic monitoring in liver transplantation [Image of intraop TEG patterns]. *Anesthesia and analgesia, 64*(9), 888–896.

Kang, Y. & Audu, P. (2006). Coagulation and liver transplantation. *International Anesthesiology Clinics, 44*(4),17-36. doi: 10.1097/01.aia.0000210811.77663.1e.

Kim, J.H. (2017). Should low central venous pressure be maintained during liver transplantation? *The Open Anesthesia Journal, 11*. doi: 10.2174/1874321801711010017

Kumar, L. (2023). Intra-operative management of transplant recipient: An overview. In V. Vohra, N. Gupta, A. S. Jolly, & S. Bhalotra (Eds.), *Peri-operative anesthetic management in liver transplantation.* Springer: Singapore. https://doi.org/10.1007/978-981-19-6045-1_18

Kumar, N., Flores, A.S., Mitchell, J., Hussain, N., Kumar, J.E., Wang, J. Fitzsimons, M., Dalia, A.A., Essandoh, M., Black, S.M., Schenk, A.D, Stein, E., Turner, K., Sawyer, T.R., Iyer, M.H. (2023). Intracardiac thrombosis and pulmonary thromboembolism during liver transplantation: A systematic review and meta-analysis. *American Journal of Transplantation, (23)*8, 1227-1240. doi: 10.1016/j.ajt.2023.04.029

Lee, J., Yoo, Y., Lee, J., Park, Y. J, Ryu, H. G. (2016). Sevoflurane versus desflurane on the incidence of postreperfusion syndrome during living donor liver transplantation: A randomized controlled trial. Transplantation 100(3), 600-606, doi:10.1097/TP.0000000000000874

Lichtenthal, P. R., & De Wolf, A. (1999). A.V.A.: A novel approach to venous access. *Critical Care, 3*(1), P059. https://doi.org/10.1186/cc434

O'Leary, J. G., Lepe, R, Davis, G. L. (2008). Indications for liver transplantation. Gastroenterology, 134(6),1765-1776. doi: 10.1053/j.gastro.2008.02.028

Mao, X., Cai, Y., Chen, Y., Wang, Y., Jiang, X., Ye, L., Li, S., (2022). Novel targets and therapeutic strategies to protect against hepatic ischemia reperfusion injury. Frontiers in Medicine, 8. doi: 0.3389/fmed.2021.757336

Magder, S. (2016). Volume and its relationship to cardiac output and venous return. *Critical Care, 20,* 271. https://doi.org/10.1186/s13054-016-1438-7

Marcus, S. G., Syed, S., Anderson, A., & Bokoch, M. P. (2024). Goal-directed therapy in liver surgery [*Image of hand mnemonic*]. *Current Anesthesiology Reports, 14,* 197–208. https://doi.org/10.1007/s40140-024-00613-4

Mehta, S., Trotter, J., & Asrani, S. (2023). Policy corner: Liver transplant MELD 3.0 [Image liver transplant policy corner: Meld 3.0]. *Liver Transplantation, 29*(9), 1006–1007. https://doi.org/10.1097/LVT.0000000000000187

Miller, R. D. (Ed.). (2015). *Miller's anesthesia* (8th ed.). Elsevier Saunders.

Millson, C., et. al. (2020). Adult liver transplantation: UK clinical guideline - part 2: Surgery and post-operation [anastomoses illustration]. British Medical Journal (BMJ), 0, 1-12, doi:10.1136/flgastro-2019-101216

Mouratidou, C., Pavlidis, E. T., Katsanos, G., Kotoulas, S. C., Mouloudi, E., Tsoulfas, G., Galanis, I. N., & Pavlidis, T. E. (2023). Hepatic ischemia-reperfusion syndrome and its effect on the cardiovascular system: The role of treprostinil, a synthetic prostacyclin analog. *World journal of gastrointestinal surgery*, *15*(9), 1858–1870. https://doi.org/10.4240/wjgs.v15.i9.1858

Mukhtar, A. & Dabbous, H. (2016). Modulation of splanchnic circulation: Role in perioperative management of liver transplant patients. World Journal of Gastroenterology, 22(4): 1582-1592. doi: 10.3748/wjg.v22.i4.1582

Mukhtar, A., Lotfy, A., Hussein, A., & Fouad, E. (2020). Splanchnic and systemic circulation cross talks: Implications for hemodynamic management of liver transplant recipients. *Best Practice & Research Clinical Anaesthesiology, 34*(1), 109–119. https://doi.org/10.1016/j.bpa.2019.12.003

Nagelhout, J. J., & Plaus, K. L. (2014). *Nurse anesthesia* (5th ed.). Elsevier/Saunders.

Newby, D.E., & Hayes, P.C. (2002). Hyperdynamic circulation in liver cirrhosis: not peripheral vasodilatation but 'splanchnic steal'. QJM : *An International Journal of Medicine, 95*(12), 827-830. https://doi.org/10.1093/qjmed/95.12.827

Nishida, S., Nakamura, N., Vaidya, A., Levi, D. M., Kato, T., Nery, J. R., & Tzakis, A. G. (2006). Piggyback technique in adult orthotopic liver transplantation: An analysis of 1067 liver transplants at a single center. *HPB: The Official Journal of the International HepatoPancreatoBiliary Association, 8*(3), 182–188. https://doi.org/10.1080/13651820500542135

Orcutt, S. T., Kobayashi, K., Sultenfuss, M., Hailey, B. S., Sparks, A., Satpathy, B., & Anaya, D. A. (2016). Portal vein embolization as an oncosurgical strategy prior to major hepatic resection: Anatomic, surgical, and technical considerations. *Frontiers in Surgery, 11*(3), 14. https://doi.org/10.3389/fsurg.2016.00014

Patel, V., & Preedy, V. (2017). *Biomarkers in liver disease.* Springer Netherlands. https://doi.org/10.1007/978-94-007-7675-3

Pérez-Calatayud, A. A., Hofmann, A., Pérez-Ferrer, A., Escorza-Molina, C., Torres-Pérez, B., Zaccarias-Ezzat, J. R., Sanchez-Cedillo, A., Manuel Paez-Zayas, V., Carrillo-Esper, R., & Görlinger, K. (2023). Patient Blood Management in Liver Transplant—A Concise Review. *Biomedicines, 11*(4), 1093. https://doi.org/10.3390/biomedicines11041093

Price, J. (2024, February 27). Referral for liver transplantation [*Pie chart of indications for OLT indications*]. *Hepatitis C Online.* https://www.hepatitisc.uw.edu/go/management-cirrhosis-related-complications/liver-transplantation-referral/core-concept/all

Quiroag, S., Sebastia, C., Castella, E., Perez-Lafuente, M., & Alvarez-Catells, A. (2002). Improved diagnosis of hepatic perfusion disorders: Value of hepatic arterial phase imaging during helical CT [*Image of hepatic blood flow*]. *RadioGraphics, 21,* 65–81.

Rando, K., Niemann, C. U., Taura, P., & Klinck, J. (2011). Optimizing cost-effectiveness in perioperative care for liver transplantation: a model for low- to medium-income countries. *Liver transplantation : official publication of the American Association for the Study of Liver Diseases and the International Liver Transplantation Society*, *17*(11), 1247–1278. https://doi.org/10.1002/lt.22405

Rhee, J. W., Zhang, S., Gallo, A., Ahmed, A., & Kawana, M. (2022). Severe cardiovascular omplications following liver transplantation in patients with iron overload. *JACC. Case reports*, *4*(11), 677–681. https://doi.org/10.1016/j.jaccas.2021.12.012

Rossetto, A., Baccarani, U., Adani, G, Lorenzin, D., Leo, C., Seriau, L., Bidinost, S., Comuzzi, C., Bresadola, V. (2012). Cardiovascular Risk Factors and Liver Transplantation. Minireview. [cardiovascular pre-op flow chart image]. *Transplantation Technologies & Research, 2*(1), doi:10.4172/2161-0991.1000109

Ruf, A, Dirchwolf, M, Feeman, R. (2022). From Child-Pugh to MELD score and beyond: Taking a walk down memory lane. Annals of Hepatology, 27(1), doi: 10.1016/j.aohep.2021.100535

Saracoglu A., Saracoglu K.T., Bilgili B. (2019). Volatile Agents and Liver Transplantation. Clinics in Medicine, 1(1). Retrieved from https://www.medtextpublications.com/open-access/volatile-agents-and-liver-transplantation-155.pdf

Segal, B. S., & Bader, A. M. (2011). PreoperativeCare and Evaluation. In C. Vacanti, S., Segal, P., Sikka, & R. Urman (Eds.), *Essential Clinical Anesthesia*. Cambridge University Press.

Shankar, J., & Vohra, V. (2023). Intraoperative coagulation monitoring in liver transplant surgery [Transfusion algorithm]. In V. Vohra, N. Gupta, A. S. Jolly, & S. Bhalotra (Eds.), *Peri-operative anesthetic management in liver transplantation.* Springer: Singapore. https://doi.org/10.1007/978-981-19-6045-1_18

Sharma, M., Somani, P., Rameshbabu, C. S., Sunkara, T., & Rai, P. (2018). Stepwise evaluation of liver sectors and liver segments by endoscopic ultrasound. *World Journal of Gastrointestinal Endoscopy, 10*(11), 326–339. https://doi.org/10.4253/wjge.v10.i11.326

Stammers, M. (2018). Imaging of the liver [Image]. *Medium.* https://medium.com/@MattStammers/imaging-the-liver-135724b415e0

Stieber, A. C., Marsh, J. W., Jr, & Starzl, T. E. (1989). Preservation of the retrohepatic vena cava during recipient hepatectomy for orthotopic transplantation of the liver. *Surgery, gynecology & obstetrics*, *168*(6), 542–544.

Terrault, N.A, Francoz, C., Berenguer, M., Charlton, M., Heimbach, J. (2023). Liver transplantation 2023: Status report, current and future challenges. Clinical Gastroenterology and Hepatology, 21(8), 2150-2166. https://doi.org/10.1016/j.cgh.2023.04.005

Trivedi H. D. (2022). The Evolution of the MELD Score and Its Implications in Liver Transplant Allocation: A Beginner's Guide for Trainees. *ACG case reports journal*, *9*(5), e00763. https://doi.org/10.14309/crj.0000000000000763

United Network for Organ Sharing (UNOS). (2015, December 8). Policy and system changes adding serum sodium to MELD calculation. https://unos.org/news/policy-and-system-changes-adding-serum-sodium-to-meld-calculation/#:~:text=Policy%20and%20system%20changes%20adding%20serum%20sodium%20to%20MELD%20calculation,-

Dec%208%2C%202015&text=At%2Da%2Dglance%3A%20On,of%20Directors%20in%20June%202014.

Vanneman, M.W., Dalia, A.A., Crowley, J.C., Luchette, K.R., Chitilian, H.V., & Shelton, K.T. (2020). A focused transesophageal echocardiography protocol for intraoperative management during orthotopic liver transplantation. Journal of Cardiothoracic and Vascular Anesthesia, 34(7), 1824-1832. DOI: 10.1053/j.jvca.2020.01.028

Vetrugno, L., Barbariol, F., Baccarani, U., Forfori, F., Volpicelli, G., & Della Rocca, G. (2017). Transesophageal echocardiography in orthotopic liver transplantation: a comprehensive intraoperative monitoring tool. Critical ultrasound journal, 9(1), 15. https://doi.org/10.1186/s13089-017-0067-y

Vetrugno, L., Cherchi, V., Lorenzin, D., De Lorenzo, F., Ventin, M., Zanini, V., Terrosu, G., Risaliti, A., Baccarani, U., & Bove, T. (2021). The challenging management of an intracardiac thrombus in a liver transplant patient at the reperfusion phase: A case report and brief literature review. *Transplantation direct*, *7*(10), e746. https://doi.org/10.1097/TXD.0000000000001200

Vitin, A. A., Tomescu, D., & Azamfirei, L. (2017). Hemodynamic optimization strategies in anesthesia care for liver transplantation. InTech.com. https://doi.org/10.5772/intechopen.68416

Wagener, G. (2012). *Liver Anesthesiology and Critical Care Medicine*. Springer: New York, NY.

Yartsev, A. (2024). Hepatic blood flow. Deranged Physiology. https://derangedphysiology.com/main/cicm-primary-exam/cardiovascular-system/Chapter-475/hepatic-blood-flow

Yehuda, R. & Ramona, N.R. (2022). Pitfalls in the hemostatic management of a liver transplantation. *Annals of Clinical Gastroenterology and Hepatology, 6*, 001-005. doi: 10.29328/journal.acgh.100103