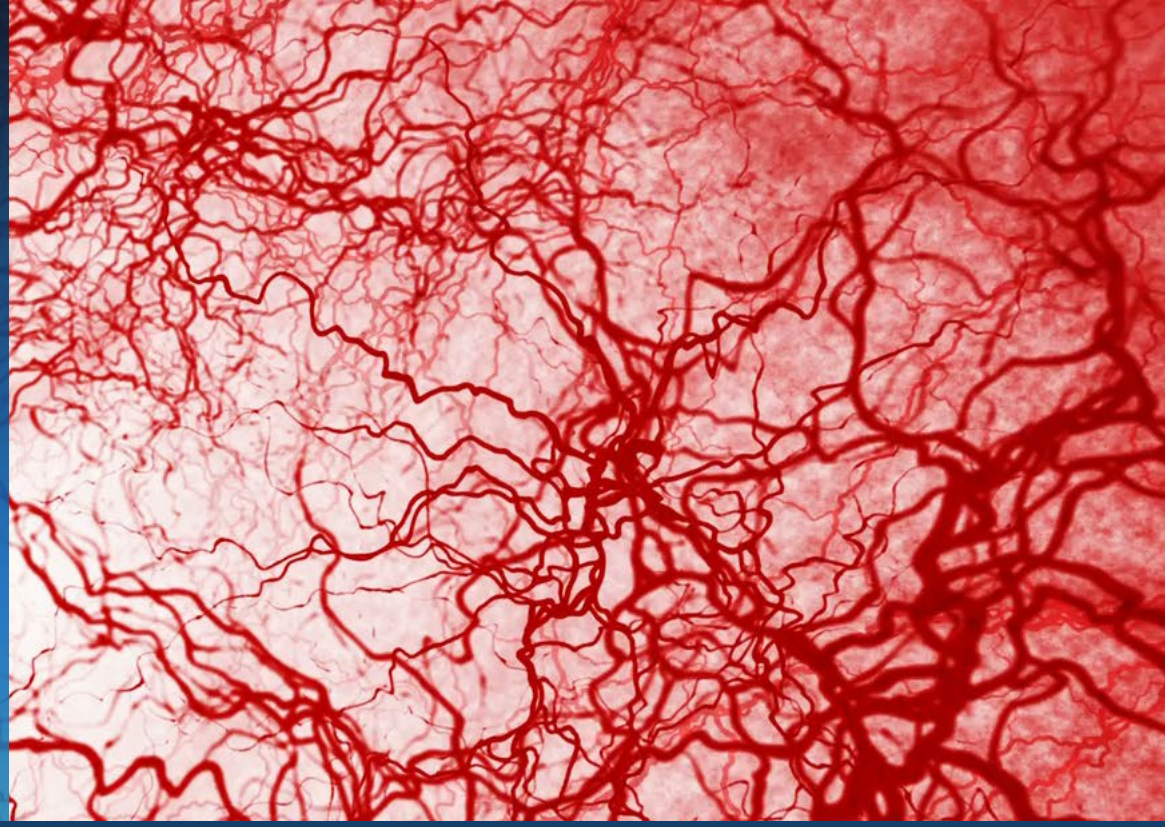
Closing Chasms and Optimizing Care in Hereditary Hemorrhagic Telangiectasia:



Expert Perspectives on the Role of Intravenous Iron in the Management of HHT-Associated IDA

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Dr. Al-Samkari also served as a planner for the activity. All other planners and reviewers had no relevant relationships to disclose. All relevant relationships have been mitigated.

Faculty Disclosures

- Hanny Al-Samkari, MD
  - **Advisory Board/Consultant:** Agios, Amgen, Alpine, Alnylam, argenx, Novartis, Pharmacosmos, Sobi
  - **Research Funding to Institution:** Agios, Amgen, Sobi, Novartis, Vaderis
- Myles Wolf, MD, MMSc
  - **Advisory Board/Consultant:** Alexion, Jnana, Pharmacosmos, Unicycive, Walden
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Learning Objectives

Take the Pre-Test!
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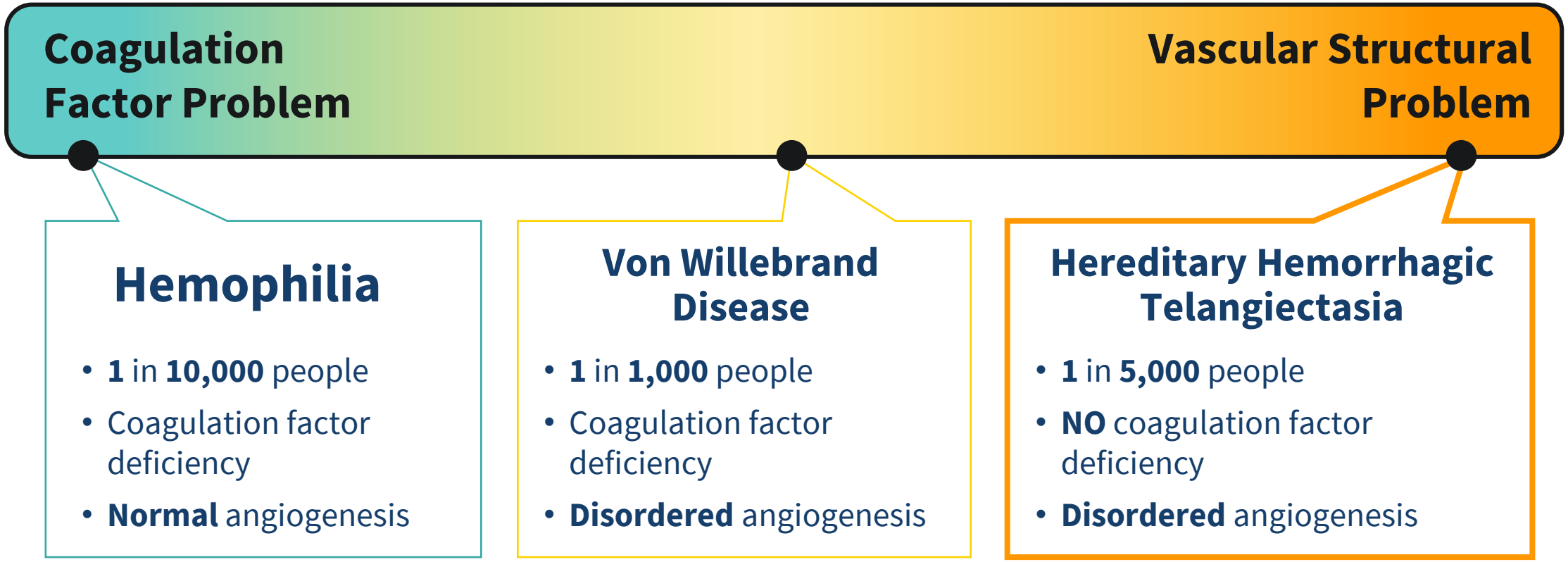
- Review epidemiologic trends and fundamental pathophysiologic principles of hereditary hemorrhagic telangiectasia (HHT), with emphasis on specific genetic etiologies
- Recognize the hallmark disease manifestations and diverse clinical presentation of HHT
- Summarize current international HHT guideline recommendations for anemia management, encompassing early and accurate diagnosis, screening protocols, and evidence-based treatment
- Examine guideline-endorsed approaches to testing and treatment of HHT-associated iron deficiency (ID) and iron deficiency anemia (IDA), with an incisive focus on iron replacement therapies
- Evaluate the clinical utility and paradigmatic placement of specific IV iron products for the treatment of HHT-associated IDA, highlighting key differentiators between available agents
- Analyze the prevalence and real-world impact of IV iron-induced hypophosphatemia

Patient Case: Part 1, Meet Jack

- **44-year-old man** presents to clinic with fatigue, reduced energy, brain fog, recurrent epistaxis, and dark stools.
  - Symptoms **are severe enough to impact work**
- Recurrent nosebleeds started in his 20s and have worsened over time
  - **Diagnosed: "mild" von Willebrand disease**
- **7 years ago**: mildly anemic, prescribed oral iron (takes on and off due to constipation and GI upset)
- **Over past 2 years**: intermittent dark stools his provider attributed to oral iron and swallowed epistaxis blood
- **Today**: Hb 8.9 g/dL, MCV 69, ferritin 9 ng/mL, TSAT 5%
  - He has taken oral ferrous sulfate daily for past 3 months

What is the most appropriate next step to diagnose Jack?

The Spectrum of (Non-Platelet) Bleeding Disorders



Ferry AM, et al. *Am J Rhinol Allergy*. 2020; https://curehht.org/understanding-hht/what-is-hht/medical-summary/; Viteri-Noel A, et al. *J Clin Med*. 2022; Zhang E, et al. *Blood Adv*. 2024.

HHT: Multisystem Hereditary Bleeding Disorder

with Numerous Morbid and Potentially Fatal Manifestations

- Progressive, multisystem bleeding disorder consequent to abnormal vessel formation
  - As such, requires a multidisciplinary and interprofessional management approach
  - Mucocutaneous telangiectasias → chronic gastrointestinal hemorrhage and severe recurrent epistaxis
  - *Severe iron deficiency (ID) and/or iron deficiency anemia (IDA)*
    - IV iron infusions or RBC transfusions
  - Visceral AVMs in lung, liver, brain, others → morbidity/mortality
- **Bleeding most important to patients**
  - AVMs and anemia tied for 2nd

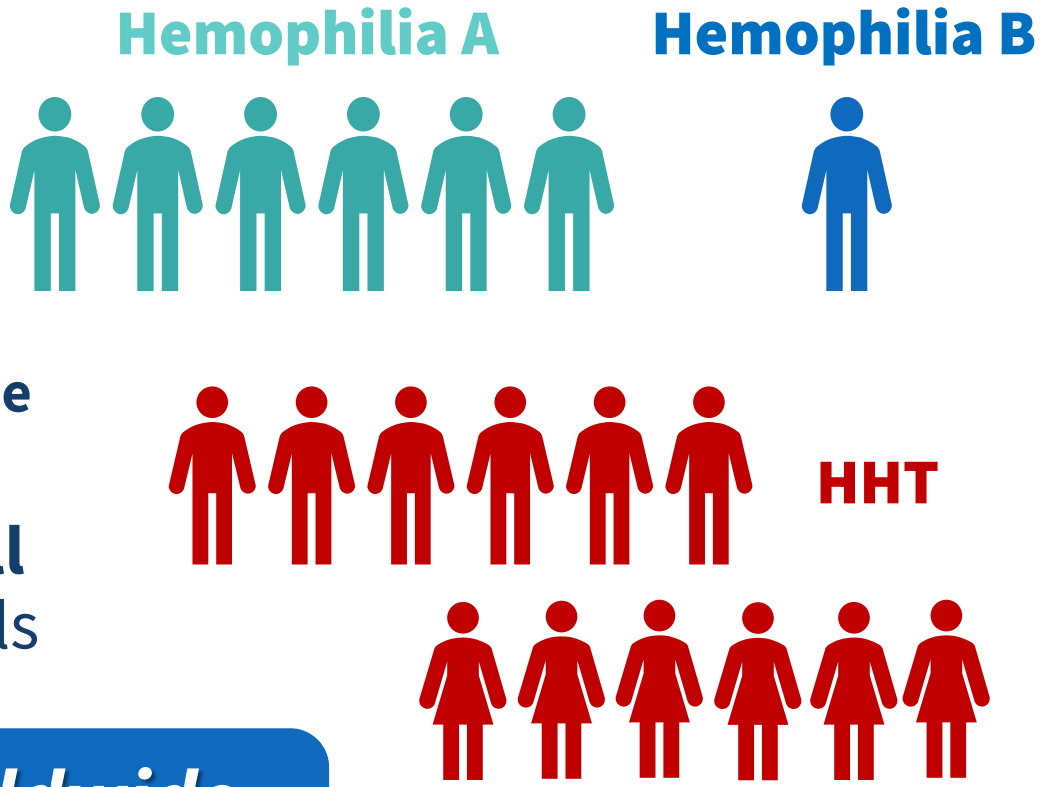
No FDA-approved therapies to-date

AVM: ArterioVenous Malformations

Viteri-Noel A, et al. *J Clin Med*. 2022; Ferry AM, et al. *Am J Rhinol Allergy*. 2020; https://curehht.org/understanding-hht/what-is-hht/medical-summary/; Faughnan M, et al. *Ann Intern Med*. 2020; Droege F, et al. *Vasc Med*. 2018; Zarrabeitia R, et al. *Health Qual Life Outcomes*. 2017; Kasthuri R, et al. *Blood Adv*. 2022; https://curehht.org/understanding-hht/what-is-hht/signs-and-symptoms/.

HHT is the Second Most Common Inherited Bleeding Disorder

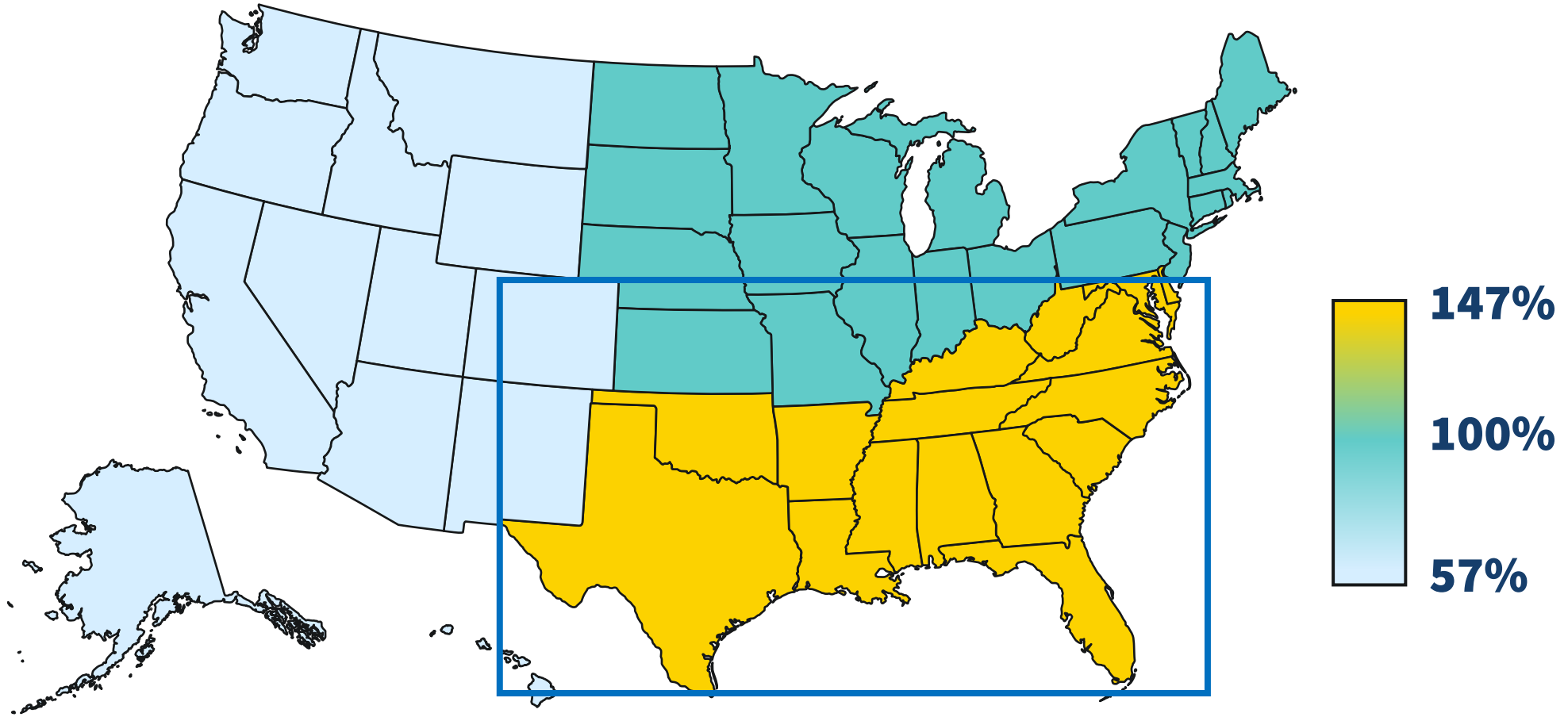
- Autosomal dominant inheritance
- 1:1 male to female prevalence
- Most clinically significant and morbid inherited bleeding disorder of women
  - **More severe bleeding and visceral disease manifestations in women**
- Patients with HHT have **reduced overall survival** compared with healthy controls



HHT Affects 1.4 Million Worldwide

Zhang E, et al. *Blood Adv.* 2024; Ferry AM, et al. *Am J Rhinol Allergy*. 2020; Viteri-Noel A, et al. *J Clin Med*. 2022; Faughnan M, et al. *Ann Intern Med*. 2020; McDonald J, et al. *Front Genet*. 2015.

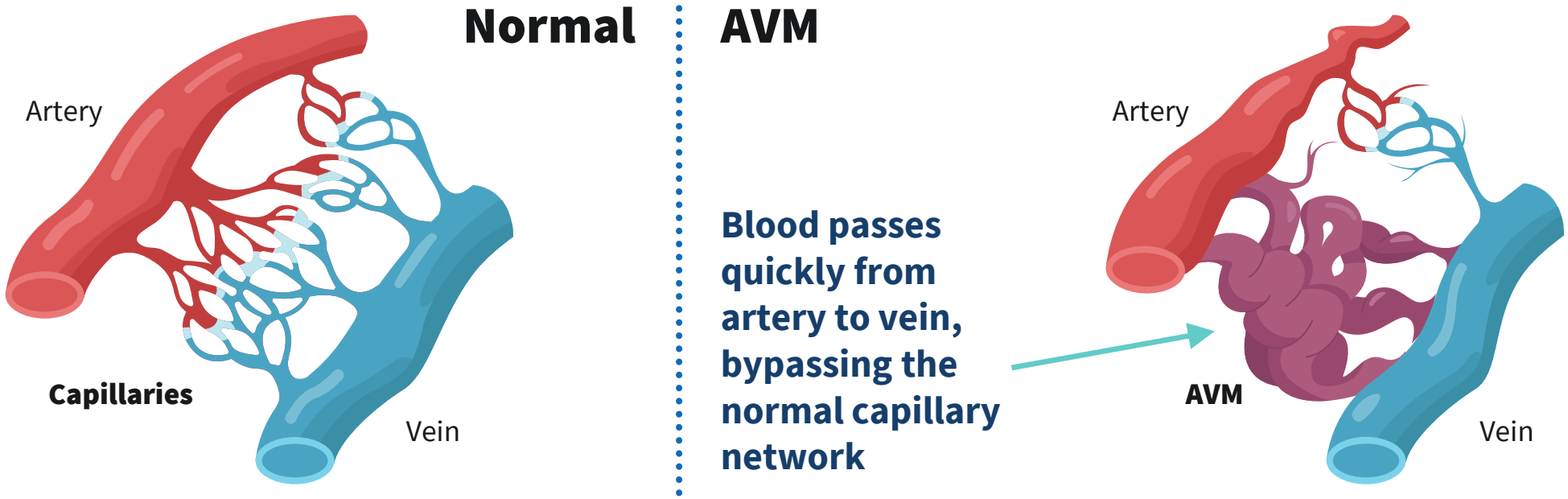
Important HHT Epidemiologic Trends



Ferry AM, et al. *Am J Rhinol Allergy*. 2020.

AVM: The Empiric Pathologic Lesion of HHT

- "**AVM**": visceral organs (lung, liver, brain, etc.)
- "**Telangiectasia**": AVM in Skin, GI mucosa, upper aerodigestive tract



Ferry AM, et al. *Am J Rhinol Allergy*. 2020; https://curehht.org/understanding-hht/what-is-hht/medical-summary/; Viteri-Noel A, et al. *J Clin Med*. 2022; Droege F, et al. *Vasc Med*. 2018.

Diagnosis of HHT is Primarily Clinical

and a MAJOR Clinical Practice Gap

- Only **10% of cases accurately diagnosed**
- Average delay in diagnosis = **27 years!**

Curaçao Criteria

- Spontaneous or recurrent **epistaxis** (nosebleeds)
- **Mucocutaneous telangiectasias** (hands, lips, face, internal mucosa of nose or mouth)
- **Visceral AVMs** (lungs, brain, liver, intestines, stomach, and/or spinal cord)
- **Family history** (first-degree relative with HHT who met the prior three criteria)

Definitive HHT Diagnosis:
3-4 Criteria

Possible HHT: 1-2 Criteria

Can (*Should Ideally*) **Confirm with Genetic Testing**

- *ENG* Mutation: HHT Type 1
- *ACVRL1* Mutation: HHT Type 2

https://curehht.org/understanding-hht/what-is-hht/signs-and-symptoms/; Viteri-Noel A, et al. *J Clin Med*. 2022; Faughnan M, et al. Ann Intern Med. 2020; McDonald J, et al. *Front Genet*. 2015; Garg N, et al. *J Blood Med*. 2014; Shovlin CL, et al. *Am J Med Genet*. 2000.

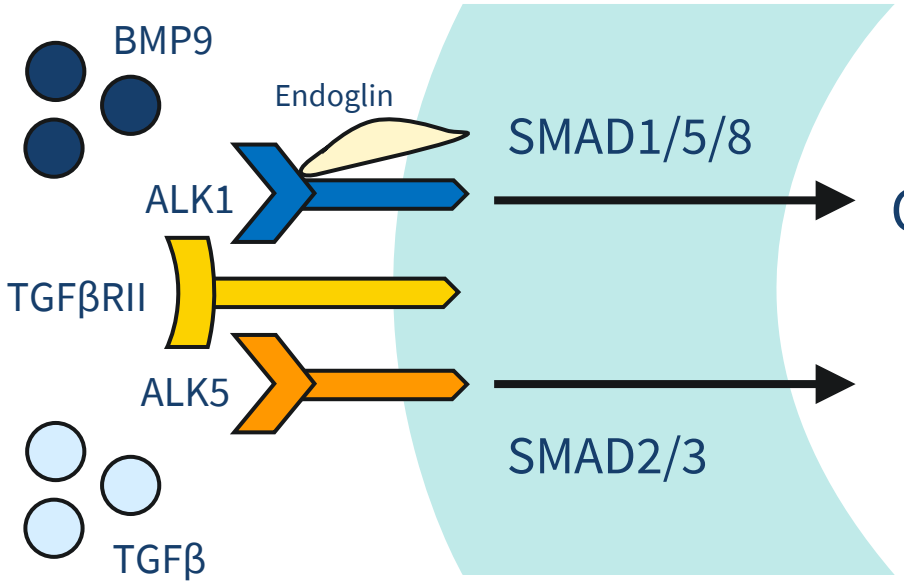
Jack's Case Continued

- Review of Jack's medical records demonstrate the following:
  - **VWF:** Ag 60%
  - **VWF:** RCo 62%
  - **FVIII:** C 68%
  - **ABO blood group:** O

- Repeat VWF testing today **confirms these numbers**.
- In addition to recurrent epistaxis, Jack has red spots (**telangiectasias**) on his fingers/lips and a **strong family history of nosebleeds**
- **Meeting 3 out of 4 Curaçao Criteria**, **Jack is diagnosed with HHT**, and the prior VWD diagnosis is removed.
- Jack **begins IV iron therapy**.

Fundamentally, HHT is a Disease of the TGF-β Signaling Pathway

Mutation in *ENG*, *ACVRL1/ALK1*, or *BMP9/GDF2* → ↓Endoglin, ↓ALK1, or ↓BMP9 leads to reduced signaling through **ALK1** and increased signaling through **ALK5** → ↑VEGF leads to increased endothelial proliferation (exacerbated by stress or hypoxia) → **AVMs** **Telangiectasias** **HHT manifestations**



Promotes endothelial cell proliferation and smooth muscle migration
Inhibits VEGF production

Inhibits endothelial cell proliferation and smooth muscle migration
Promotes VEGF production

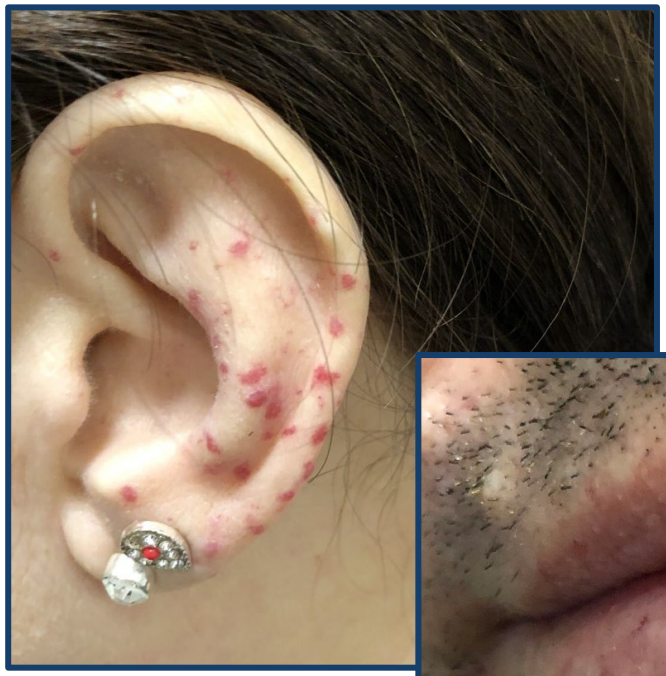
Kritharis A, et al. *Haematologica*. 2018; Viteri-Noel A, et al. *J Clin Med*. 2022; McDonald J, et al. *Front Genet*. 2015.

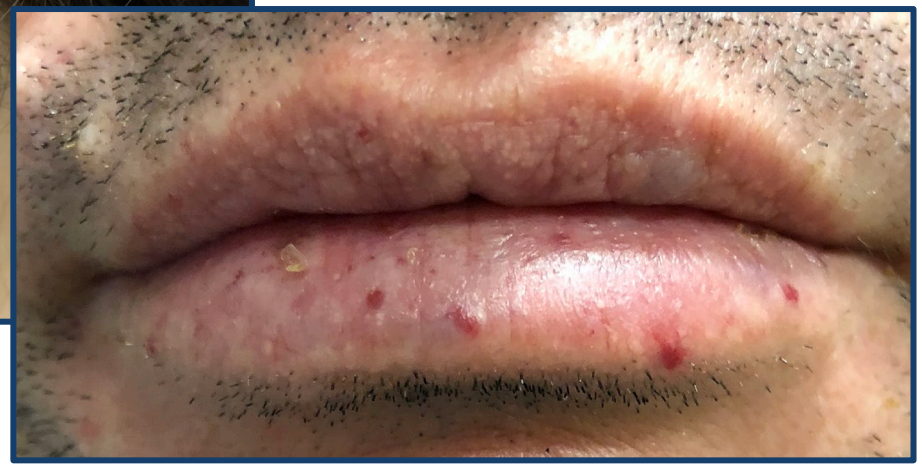
Classifying HHT Disease Subtypes

Disease	Genetic Mutation (locus)	Primary Visceral Manifestations
HHT type 1	*ENG* (9q34.11)	• Pulmonary AVMs • Brain AVMs
HHT type 2	*ACVRL1* (ALK1;12q13.13)	• Liver AVMs • Pulmonary hypertension • Spinal AVMs
JP-HHT (Combined syndrome of HHT and juvenile polyposis)	*MADH4* (SMAD4; 18q21.2)	• Gastrointestinal polyps • Visceral AVMs • Pulmonary hypertension

Kritharis A, et al. *Haematologica*. 2018; McDonald J, et al. *Front Genet*. 2015.

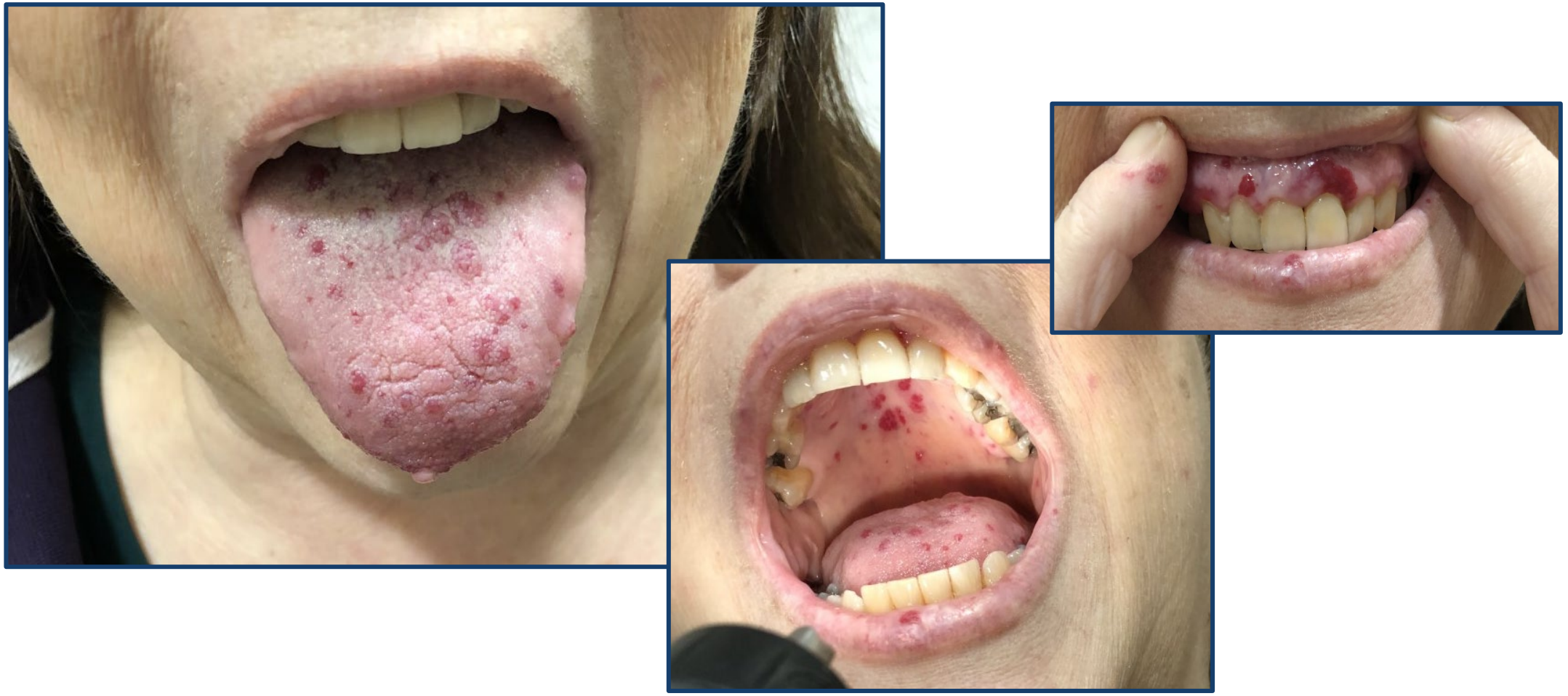
Mucocutaneous Telangiectasias: Skin





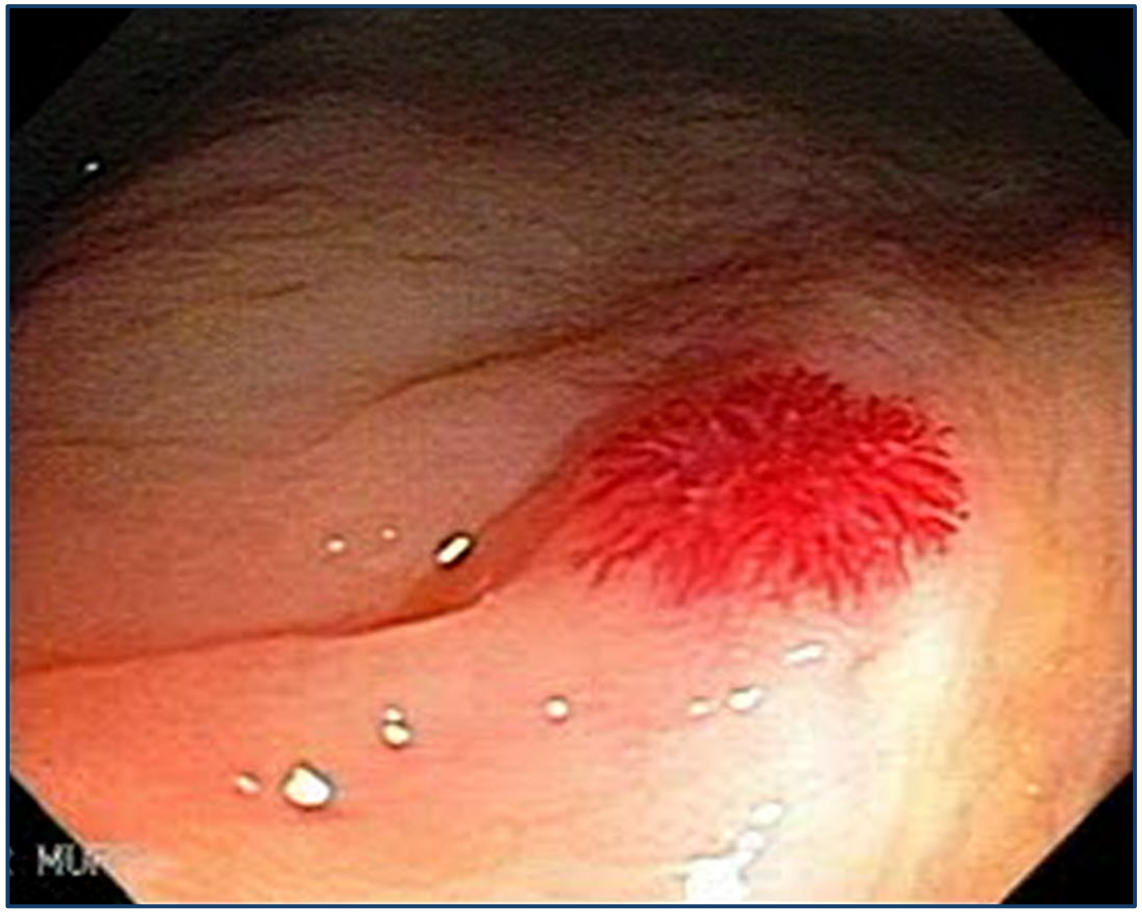
Images provided courtesy of Dr. Hanny Al-Samkari.

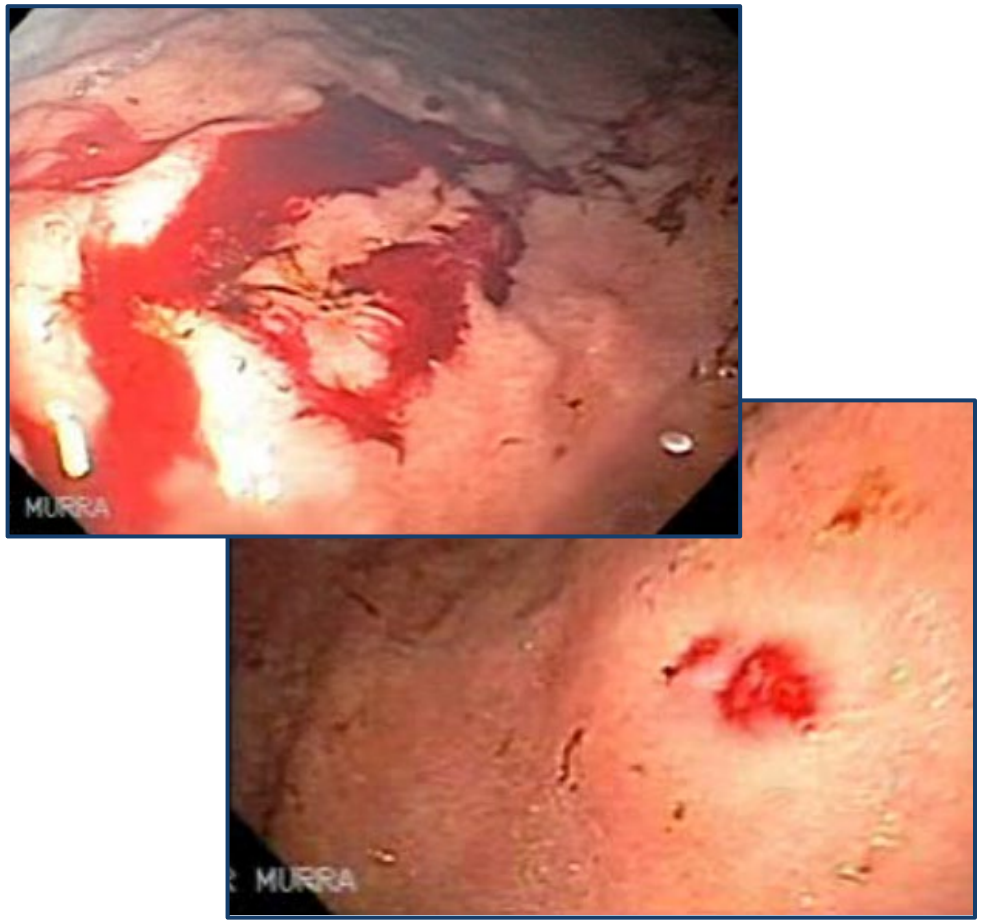
Mucocutaneous Telangiectasias: Oral Cavity



Images provided courtesy of Dr. Hanny Al-Samkari.

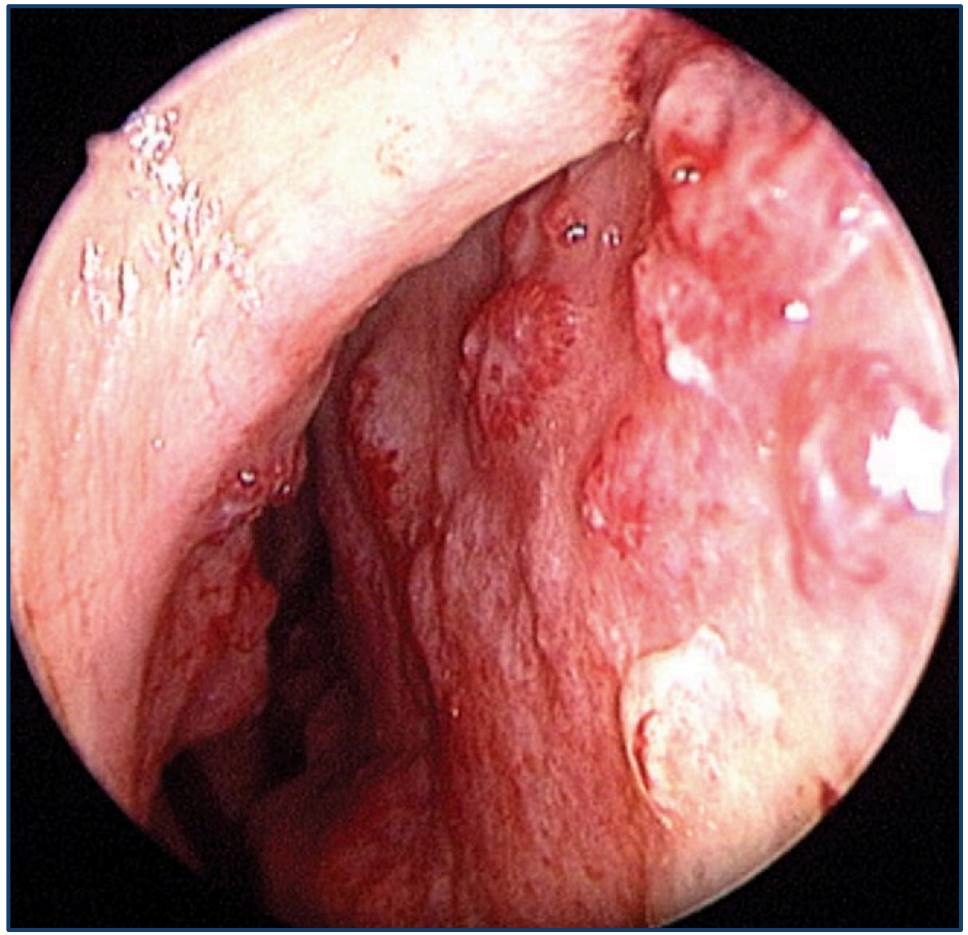
Mucocutaneous Telangiectasias: GI Tract

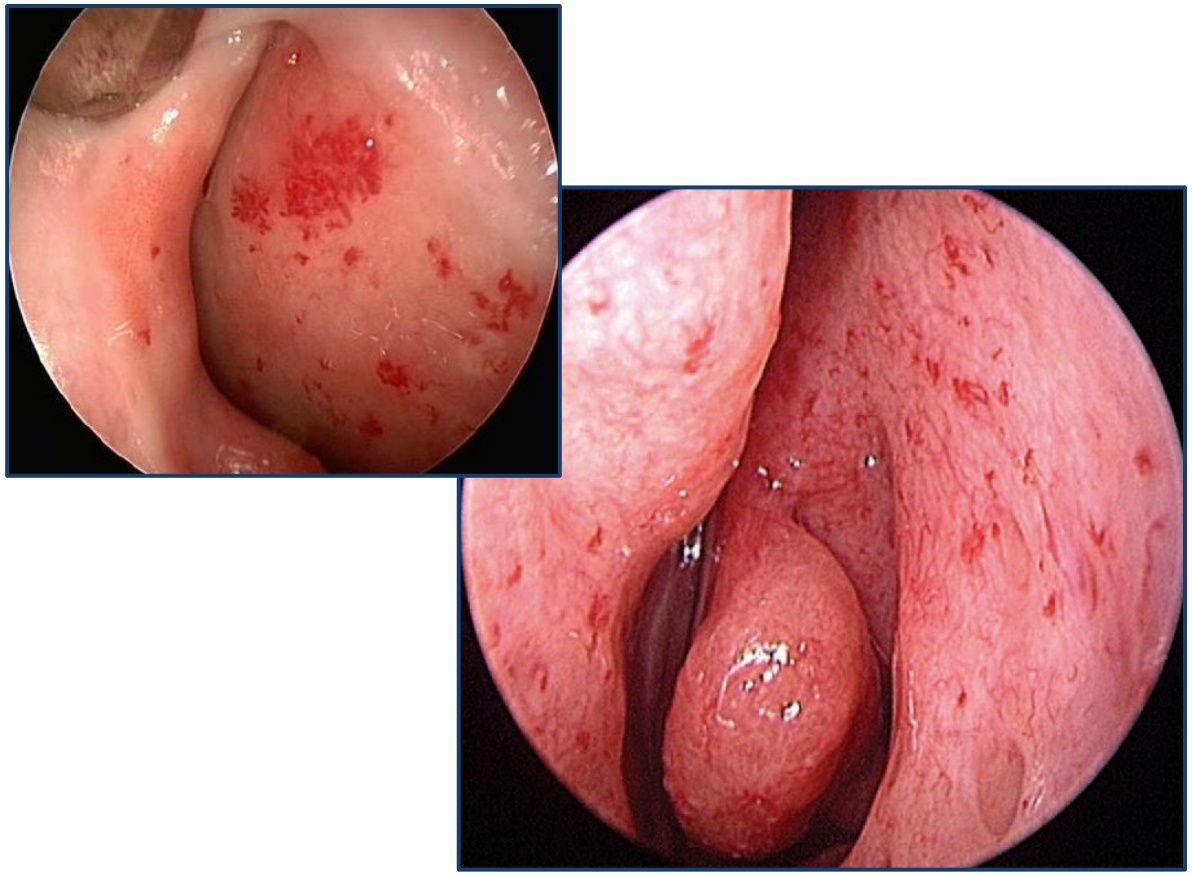




Images provided courtesy of Dr. Hanny Al-Samkari.

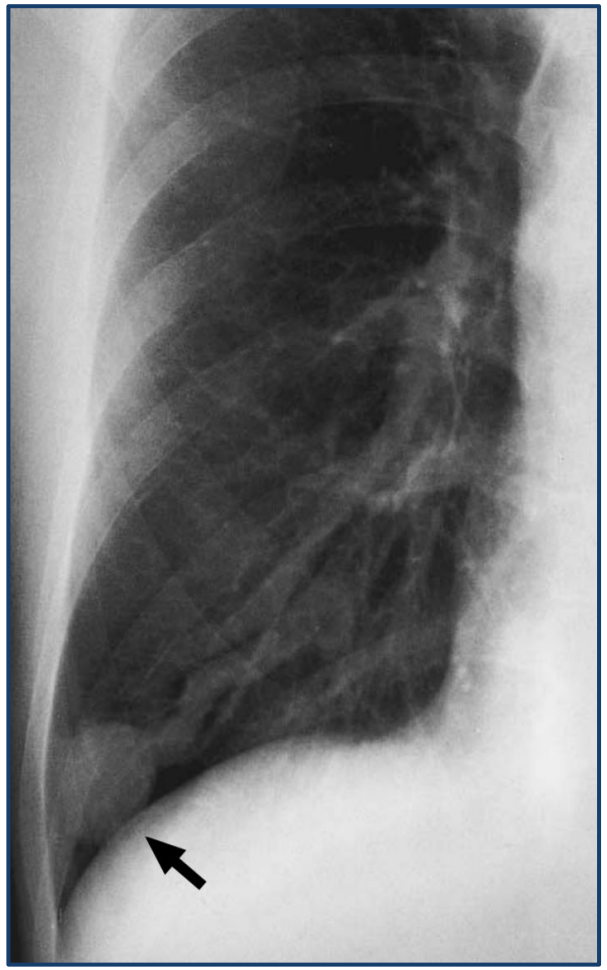
Mucocutaneous Telangiectasias: Nasal Cavity

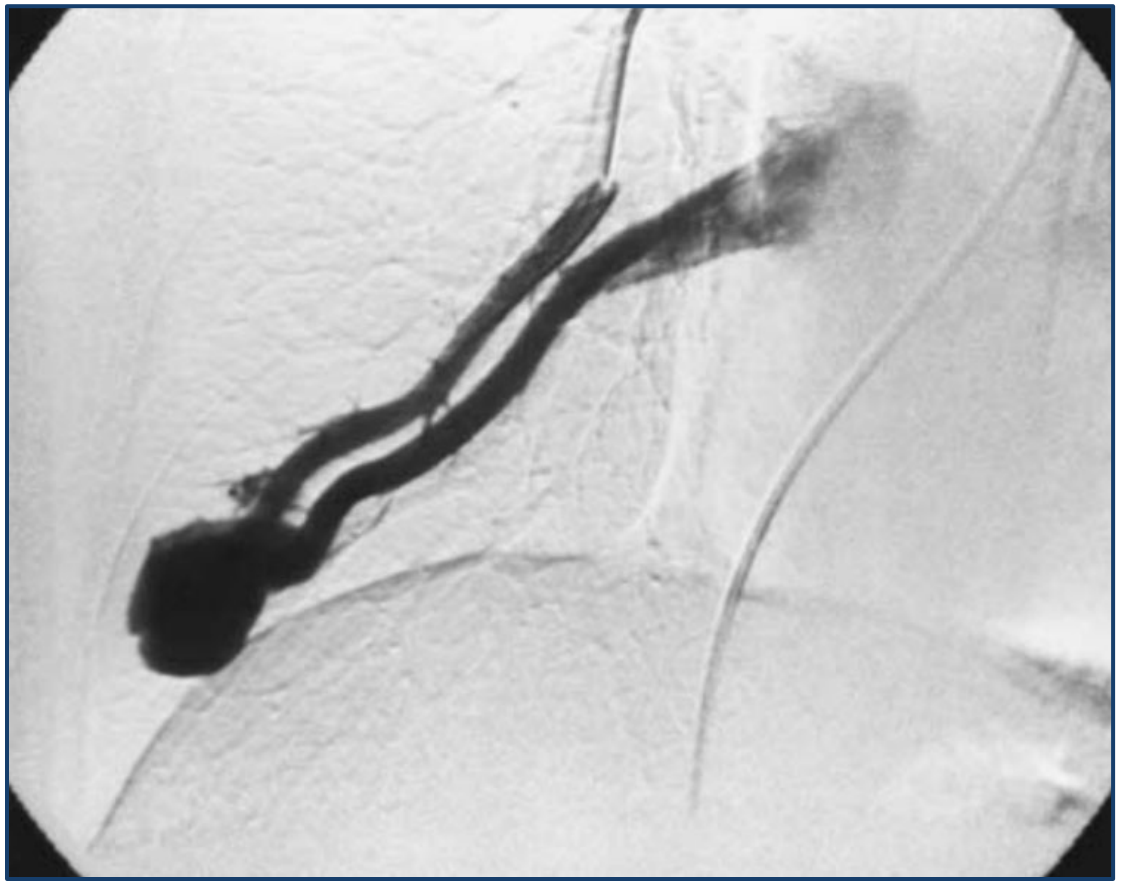




Images provided courtesy of Dr. Hanny Al-Samkari.

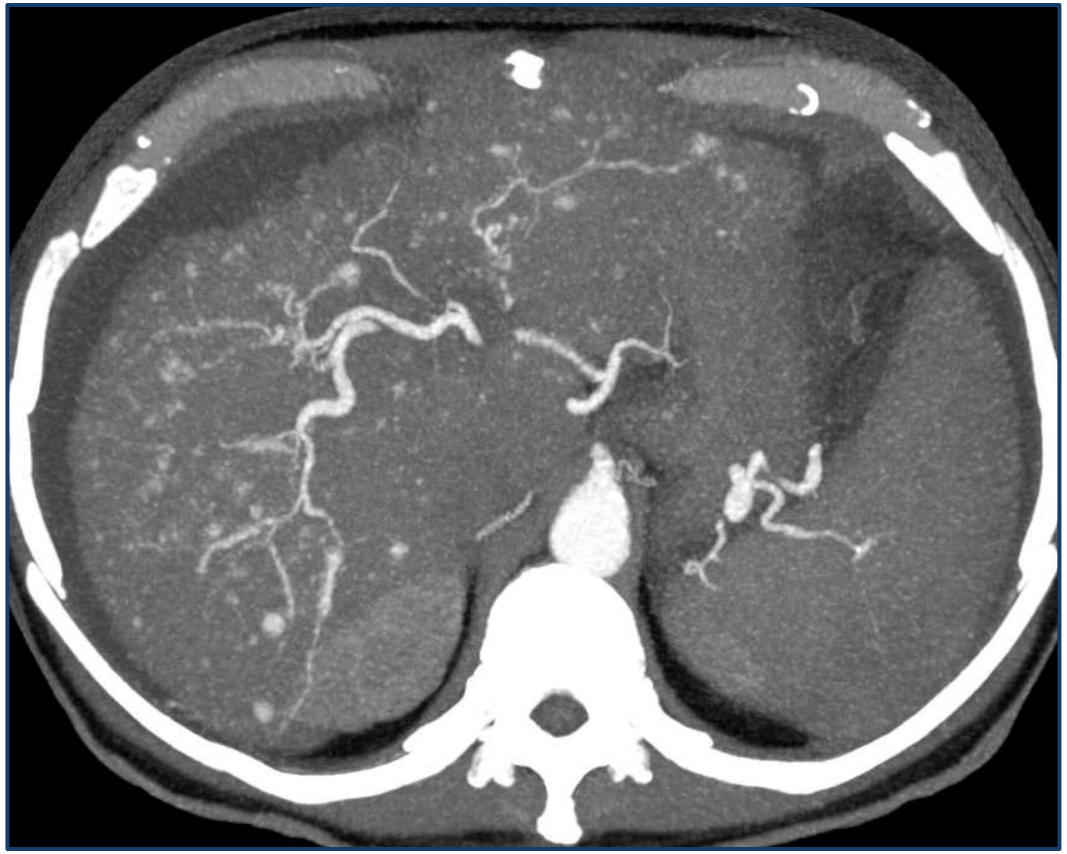
Pulmonary AVMs (>50%)

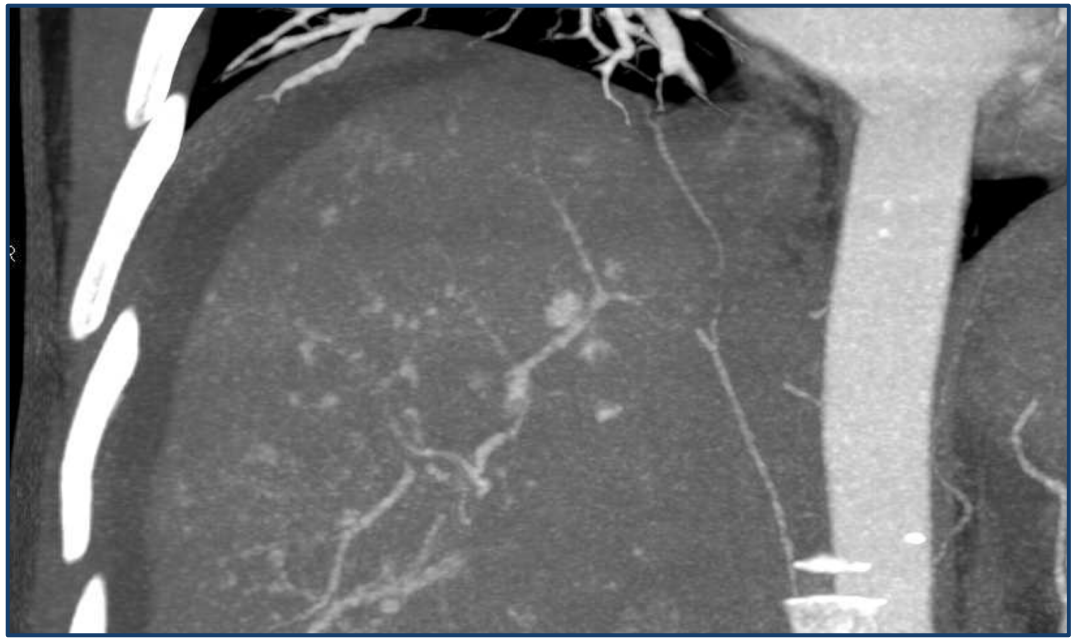




Images provided courtesy of Dr. Hanny Al-Samkari; Viteri-Noel A, et al. *J Clin Med*. 2022; Faughnan M, et al. *Ann Intern Med*. 2020; McDonald J, et al. *Front Genet*. 2015; Droege F, et al. *Vasc Med*. 2018.

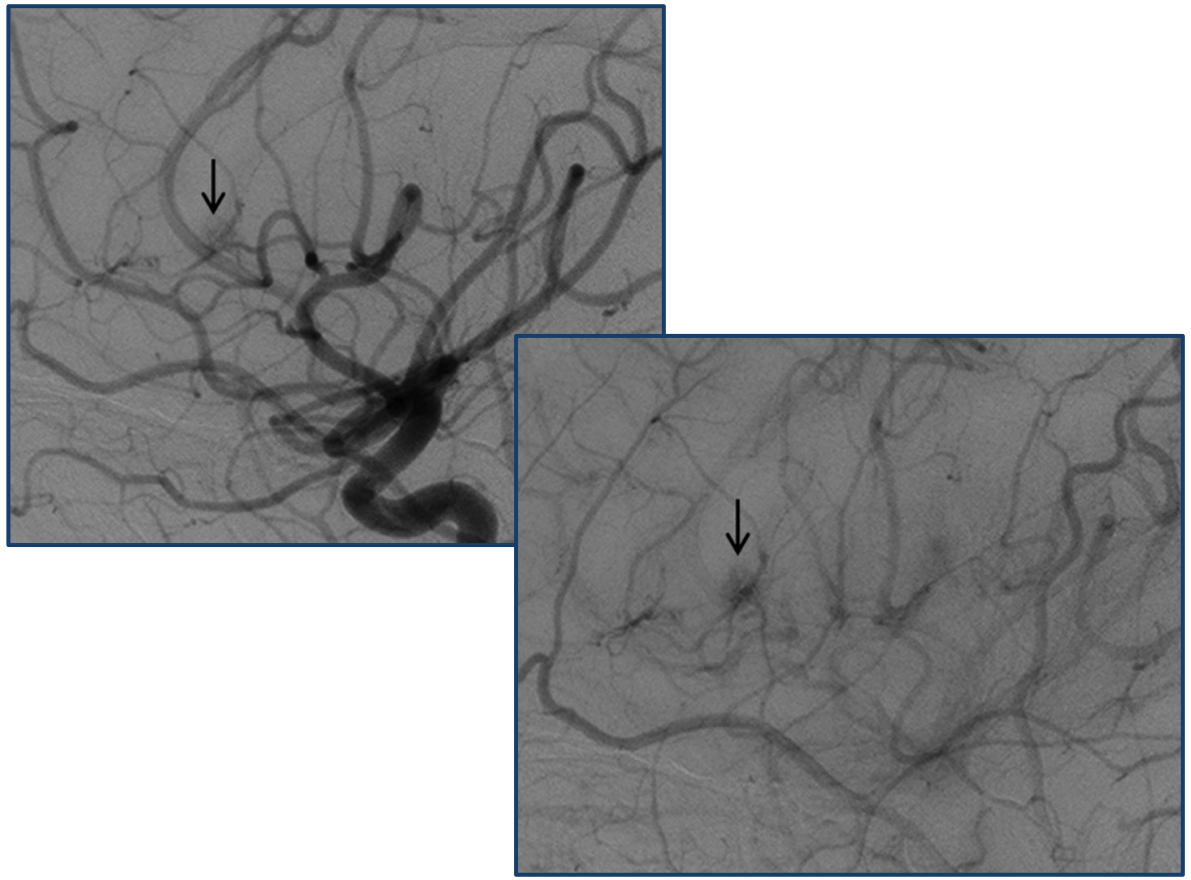
Hepatic AVMs (~70%)

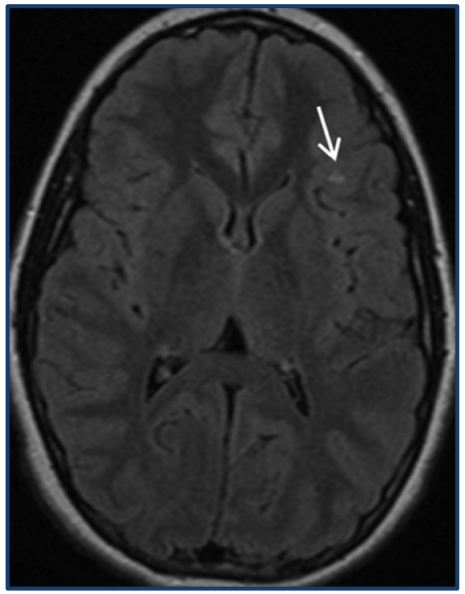


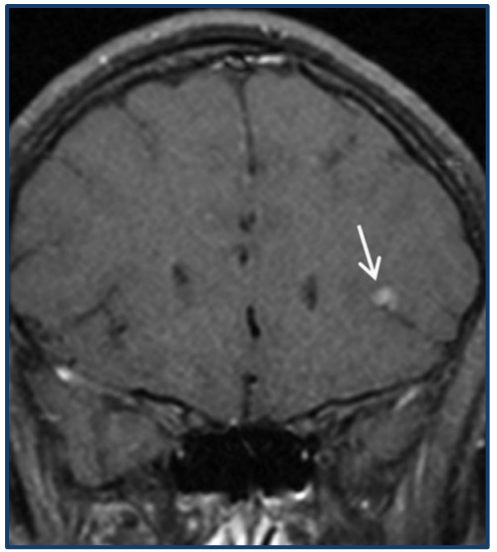


Images provided courtesy of Dr. Hanny Al-Samkari; Viteri-Noel A, et al. *J Clin Med*. 2022; Faughnan M, et al. *Ann Intern Med*. 2020; McDonald J, et al. *Front Genet*. 2015; Droege F, et al. *Vasc Med*. 2018.

Brain AVMs (~10-20%)







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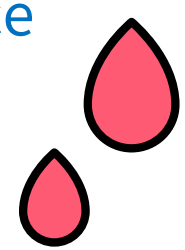
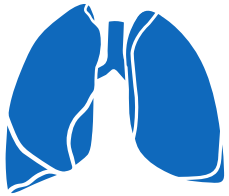
Telangiectasias are Fragile and Bleed, Acutely and Chronically

- Recurrent, severe epistaxis: **50% of children, >95% of adults**
  - Common to have **multiple nosebleeds daily**
  - Not uncommon to have an hour or more of nose bleeding daily
  - Result: **ID/IDA, social isolation, unemployment, no travel, depression, anxiety, PTSD**
- GI telangiectasias are present in 75% → **chronic GI bleeding in ~50%**
  - May result in severe anemia, RBC transfusion, and IV iron dependence
- **50% of patients with HHT have *chronic IDA***
  - May be an underestimation due to lack of screening



Viteri-Noel A, et al. *J Clin Med*. 2022; Faughnan M, et al. *Ann Intern Med*. 2020; Droege F, et al. *Vasc Med*. 2018; Jackson SB, et al. *Dig Dis Sci*. 2017; https://curehht.org/understanding-hht/what-is-hht/medical-summary/.

Recommended AVM Workup

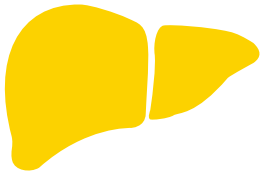


Pulmonary AVMs
(pAVMs)

- All patients should have an **echocardiogram with agitated saline contrast ("echo bubble study")** to screen for pAVMs
- **Repetition necessary** every few years

Brain AVMs
(bAVMs)

- All patients should have **brain MRI** to screen for bAVMs
- **If negative, probably do not need to repeat** unless patient develops concerning symptoms



Hepatic AVMs
(hAVMs)

- **Liver imaging** (i.e., doppler ultrasound) to screen for hAVMs is controversial but currently recommended

Viteri-Noel A, et al. *J Clin Med*. 2022; Faughnan M, et al. *Ann Intern Med*. 2020; Garg N, et al. *J Blood Med*. 2014.

Jack's Case Continued

- Jack undergoes echo with bubble study, brain MRI, and doppler ultrasound of liver
  - **Two brain AVMs are found**
  - Jack referred to neurology for evaluation
- He continues IV iron therapy, **initially with ferumoxytol**
  - He receives 4 infusions, 510 mg per infusion, administered over 4 weeks
  - Hb: 11.2 g/dL (an improvement from 8.9 g/dL, but suboptimal)
  - **Remains anemic and serum ferritin/TSAT are low = IDA**
- Epistaxis severity: moderate
- Jack's refractory anemia is disproportionate to the severity of his nosebleeds, so he undergoes endoscopy
  - **Reveals telangiectasias throughout stomach and small bowel**
  - **None are actively bleeding, so no intervention is undertaken**

Jack's Case Continued

- Jack feels "a lot better" after receiving IV iron, but lives far from the infusion center
- He asks you…

Is it possible to receive more IV iron with each infusion?

Second International HHT Guidelines

INTERNATIONAL HHT GUIDELINES

Iron Deficiency and Anemia

Recommendation #1

The following HHT patients should be **tested for iron deficiency and anemia**:

- All adults, regardless of symptoms.
- All children with recurrent bleeding and/or symptoms of anemia.

Quality of Evidence:
High
(Agreement 98%)

Strength of Recommendation:
Strong
(Agreement 96%)

Faughnan M, et al. *Ann Intern Med.* 2020; https://www.hhtguidelines.org/anemia.

Screening for Iron Deficiency in HHT

- CBC, serum ferritin, iron/total iron binding capacity (TIBC), transferrin saturation (TSAT)
- Bleeding, and risk for/severity of anemia, is a moving target
  - Often worsens with age, entering menopause
- Screening interval should always mirror bleeding symptoms
  - ***When in doubt, screen more often at first***
  - Can always space out interval later

Faughnan M, et al. *Ann Intern Med.* 2020; https://www.hhtguidelines.org/anemia.

Iron Deficiency and Anemia

Recommendation #2

Iron replacement for treatment of iron deficiency and anemia as follows:

- Initial therapy with **oral iron**
- **IV iron** replacement for when oral is not effective, not absorbed or not tolerated, or for patients presenting with severe anemia

Quality of Evidence:
Moderate
(Agreement 88%)

Strength of Recommendation:
Strong
(Agreement 100%)

Faughnan M, et al. *Ann Intern Med.* 2020; https://www.hhtguidelines.org/anemia.

Oral Iron in HHT

- Start with **one pill once daily**
- **35-65 mg of elemental iron**
- If inadequate, but well-tolerated, **go to twice daily dosing**

- Take **in between meals** → 2 hours before or 1 hour after
- Co-prescribe **stool softener**

- If not tolerated, consider another formulation (success unlikely) and/or every-other-day dosing

- Expect **>1.0 g/dL improvement** in hemoglobin (Hb) within **4-6 weeks**
  - **Anything less = clinically insufficient for an HHT patient with IDA**

Faughnan M, et al., *Ann Intern Med.* 2020; https://www.hhtguidelines.org/anemia.

IV Iron in HHT

NO

↑Hb by >1 g/dL within **4-6 weeks?**

NO

Normalized Hb and iron studies (ferritin >100 ng/mL, TSAT >20%) within **~10 weeks?**

YES

Tolerability a concern?

Initiate IV Iron

- ***Low threshold for initiating IV iron in HHT***
- If degree of iron losses are not adequately replaced by diet +/- PO iron, intermittent ongoing IV iron is requisite

Auerbach M, et al. *Lancet Haematol*. 2020; Lopez A, et al. *Lancet*. 2016; DeLoughery TG. *Acta Haematol.* 2019; Faughnan M, et al. *Ann Intern Med.* 2020; https://www.hhtguidelines.org/anemia.

IV Iron in HHT

Determine Dose

- Calculate total body iron deficit (using Ganzoni formula)

OR

- Administer 1000 mg empirically and recheck CBC and iron studies after 3-4 weeks

Once Receiving IV Iron

- Monitor serum ferritin, TSAT (Q1-3 months) to determine appropriate infusion interval
- Repeat infusion when serum ferritin <50-70 ng/mL, transferrin saturation <20-25%

- In HHT, **do not wait until patient is iron deficient or anemic again to re-treat**
- **Longitudinal repeat/regular IV iron infusions are usually needed** in HHT

Ganzoni AM. *Schweiz Med Wochenschr*.1970; Auerbach M, et al. *Lancet Haematol*. 2020; Lopez A, et al. *Lancet*. 2016; Faughnan M, et al. *Ann Intern Med.* 2020; https://www.hhtguidelines.org/anemia.

Differentiating IV Iron Products for HHT

Current FDA Labels

Iron Product	Dosing and Administration	Approved Indications	Common Adverse Drug Effects	Warnings
Low-Molecular-Weight Iron Dextran	• 100 mg daily via IV push over at least 2 minutes • Total dose is calculated based on iron deficit • May repeat daily	Iron deficiency (ID) in adult and pediatric patients 4 months of age and older for whom oral therapy is unsatisfactory or intolerable	Pruritis, abdominal pain, nausea, vomiting, diarrhea	**Black box**: risk for anaphylactic-type reactions, including fatalities
FMX	• 510 mg via IV infusion over at least 15 minutes • 2nd (510 mg) dose 3–8 days later	Iron deficiency anemia (IDA) in adult patients who have intolerance or unsatisfactory response to oral iron, or who have a diagnosis of CKD	Dizziness, hypotension, constipation, nausea	**Black box**: fatal and serious hypersensitivity reactions, including anaphylaxis
FDI	• For patient weighing ≥ 50 kg, give 1,000 mg (*single dose TDI*) over at least 20 minutes • For patients weighing <50 kg, give 20 mg/kg in a single dose	IDA in adult patients who have intolerance or unsatisfactory response to oral iron, or who have non–hemodialysis-dependent CKD	Nausea, injection site reactions, rash, hypotension	Hypersensitivity reactions, iron overload

FDA Prescribing Information.

Differentiating IV Iron Products for HHT

Current FDA Labels

Iron Product	Dosing and Administration	Approved Indications	Common Adverse Drug Effects	Warnings
Iron Sucrose	• 100–400 mg, by setting • Doses may be repeated based on clinical response and iron indices	IDA in adult and pediatric patients (2 years of age and older) with CKD	Diarrhea, nausea, vomiting, headache, hypotension, pruritus	Hypersensitivity reactions, hypotension, iron overload
FCM	• For patients weighing ≥50 kg, may give 15 mg/kg up to 1,000 mg (*single-dose TDI*) or 750 mg infusion over at least 15 minutes • If 750 mg is given, may be repeated in 7 days, for a total dosage per course of 1,500 mg • For patients weighing <50 kg, give 15 mg/kg in 2 doses, separated by at least 7 days	IDA in patients 1 yo and older who have intolerance or unsatisfactory response to oral iron, and in adults who have non–dialysis-dependent CKD (NDD-CKD) ID in adult patients with heart failure and NYHA class II/III to improve exercise capacity	Nausea, hypertension, ***hypophosphatemia***, flushing	Hypersensitivity reactions, ***symptomatic hypophosphatemia***, hypertension
Sodium Ferric Gluconate	• 125 mg (adults) via IV infusion over 1 hour, per dialysis • 1.5 mg/kg in peds • Repeated weekly for up to 8 weeks	IDA in patients 6 years old and older who are receiving hemodialysis and supplemental EPO therapy for *CKD*	Chest pain, leg cramps, dizziness, dyspnea, nausea, vomiting, diarrhea	Hypersensitivity reactions, hypotension, iron overload, benzyl alcohol toxicity

FDA Prescribing Information.

Differentiating IV Iron Products for HHT

Total Dose Infusion (TDI) Capacity by IV Iron Product

Iron Product	TDI *on the Label*	TDI *in the Clinic*
Low-Molecular-Weight Iron Dextran	No	Yes
FMX	No	Yes
FCM	Yes	Yes
FDI	Yes	Yes

HHT Guidelines Advise Against*

FCM, ferric carboxymaltose; FDI, ferric derisomaltose; FMX, ferumoxytol

**Due to high risk for IV iron-induced hypophosphatemia*

TDI always preferred in HHT

Faughnan M, et al. *Ann Intern Med.* 2020; Avni T, et al. *Mayo Clin Proc.* 2015; Wang C, et al. *JAMA*. 2015; DeLoughery TG. *Acta Haematol*. 2019; Adkinson NF, et al. *Am J Hematol*. 2018; Abdulrehman J, et al. *Transfusion*. 2019; Glaspy JA, et al. *Adv Ther*. 2021; Auerbach M, et al. *Am J Hematol*. 2021; Wolf M, et al. *JCI Insight*. 2018; Kalantar-Zadeh K, et al. *Am J Hematol*. 2021; Wolf M, et al. *JAMA*. 2020.

Ferric Carboxymaltose (FCM) Label Update

January 3, 2025

HHT formally added to product label as a "possible risk factor" for *FCM-induced hypophosphatemia*:

- *"Symptomatic hypophosphatemia with serious outcomes including osteomalacia and fractures requiring clinical intervention has been reported in patients treated with FCM in the post-market setting…possible risk factors for hypophosphatemia include…hereditary hemorrhagic telangiectasia (HHT). Check serum phosphate levels…in any patient who receives a second course of FCM within three months."*

FDA Prescribing Information.

Iron Deficiency and Anemia

Recommendation #3

RBC transfusions in the following settings:

- Hemodynamic instability/shock
- Comorbidities that require a higher Hb target
- Need to increase the Hb acutely, such as prior to surgery or during pregnancy
- Inability to maintain an adequate Hb despite frequent IV iron infusions

Quality of Evidence:

Low

(Agreement 92%)

Strength of Recommendation:

Strong

(Agreement 100%)

Faughnan M, et al. *Ann Intern Med.* 2020; https://www.hhtguidelines.org/anemia.

Iron Deficiency and Anemia

Recommendation #4

Consider evaluation for additional causes of anemia if inadequate response to iron replacement:

- **Consider:** folate, B12, MCV, smear, reticulocyte counts, TSH, hemolysis workup
- In **unresolved cases**, **hematology referral is appropriate**

Quality of Evidence:
Low
(Agreement 100%)

Strength of Recommendation:
Strong
(Agreement 100%)

Faughnan M, et al. *Ann Intern Med.* 2020; https://www.hhtguidelines.org/anemia.

Jack's Case Continued

- Jack switched to FCM: 750 mg given over 15 min infusion
- After 2 infusions (7 days apart), Hb normalized to 14.8 g/dL, ferritin 67 ng/mL, and TSAT 24%
- Systemic **bevacizumab, a disease-modifying therapy in HHT,** initiated due to severity of ongoing epistaxis and GI bleeding to reduce chronic blood loss
  - Bevacizumab is successful and IV iron frequency is reduced from **750 mg/month** to **750 mg/every 4 months**
- **With IDA and bleeding improved, Jack resumes working full time**

Summary

- Chronically bleeding HHT patients nearly always require iron supplementation
- Mild bleeding can be addressed with oral iron alone in some cases
  - Limited efficacy and tolerability concerns limit utility for many patients
- **The majority of HHT patients will require IV iron**
- Patients requiring IV iron once usually need it again and again, so products with TDI capacity should be preferenced
- Interval for IV iron infusion is patient-dependent and a moving target

Summary

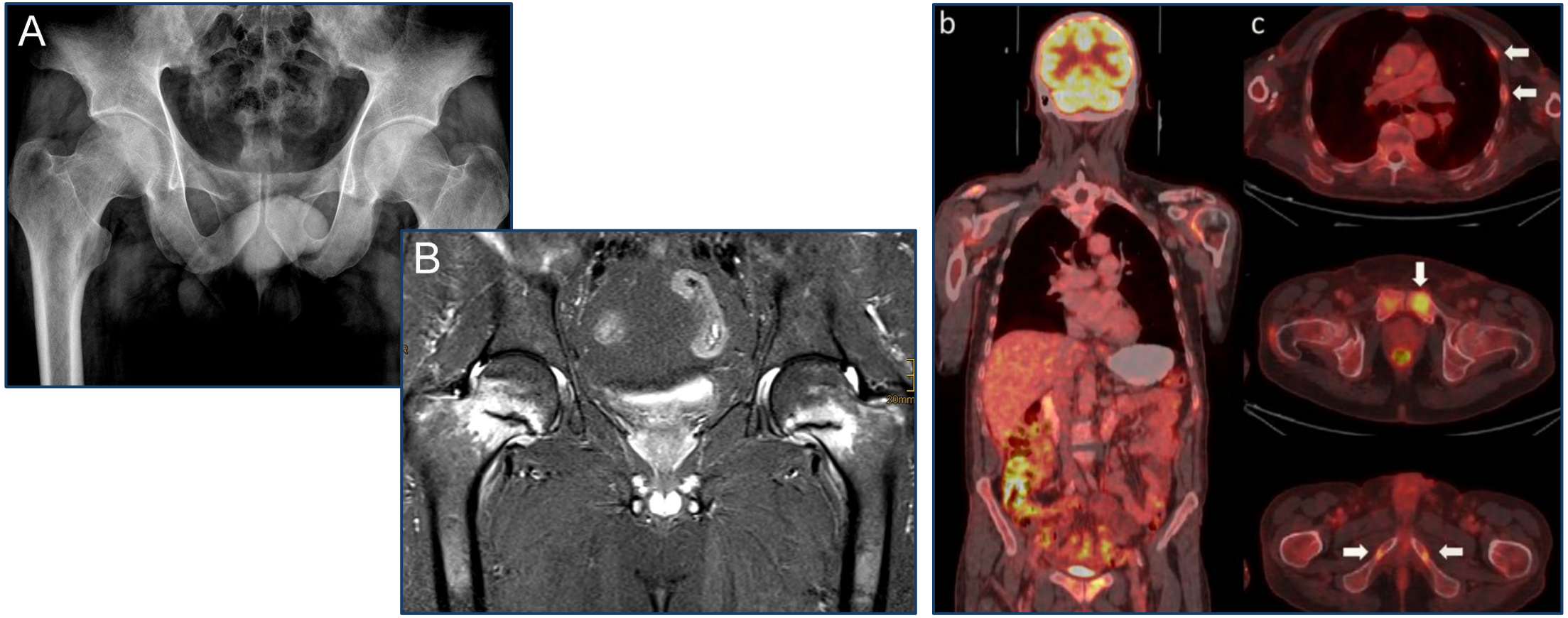
- Any HHT patient with ID/IDA requiring IV iron should receive 1000-1500 mg IV iron at minimum to replete iron stores
- Clinical pearl: I use a **ferritin of <50 ng/mL** or **transferrin saturation of <20%** as a **trigger for IV iron repletion in non-anemic patients** (i.e., those with ID, not IDA) **with chronic bleeding** (and give ~1000 mg elemental iron at this time)

Jack's Case Continued

- 6 months later, Jack returns to clinic: IDA/bleeding still under control and sustained improvements in fatigue and brain fog
- However, he reports **recent-onset bilateral groin pain**
  - Began at work about 2 months ago as a "twinge"
  - Has since gotten progressively worse
- Lab results from recent hospitalization
  - **iFGF23:** 173 pg/mL
  - **Serum phosphate:** 1.8 mg/dL
- **Physical exam:** waddling gait and grimacing with movement
  - Jack's pain is acute, and at times during the exam, quite severe

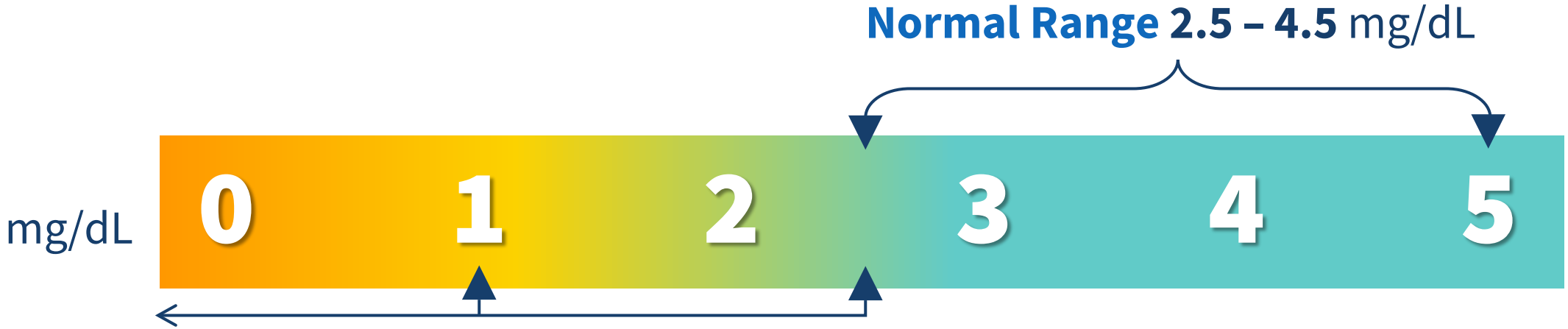
You decide to conduct further testing, including imaging, to elucidate the cause

Jack's Imaging Results



Schaefer B, et al, *Gastroenterology*. 2017; Callejas-Moraga EL, et al. *Bone Rep.* 2020.

Hypophosphatemia



<1.0 mg/dL

Risk Zone for <u>Severe</u> <u>Acute</u> Complications:

Musculoskeletal
Cardiac dysfunction
Respiratory failure
Hemolysis

<2.5 mg/dL

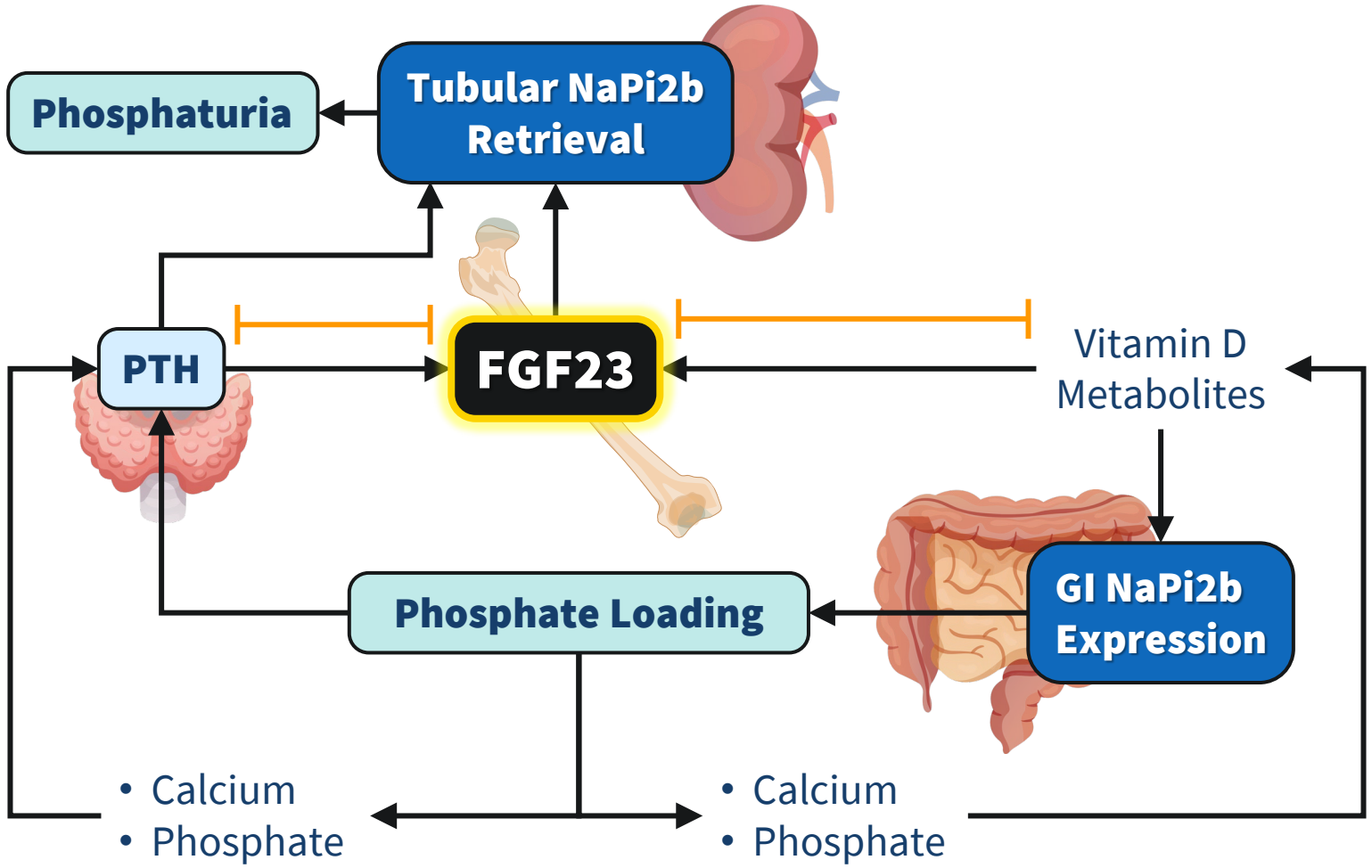
Risk Zone for <u>Long-Term</u> Complications:

Primarily Musculoskeletal

Felsenfeld AJ, Levine BS. *Am J Kidney Dis.* 2012; Kalantar-Zadeh K, et al. *Am J Hematol.* 2021; Glaspy J, et al. *Adv Ther.* 2021.

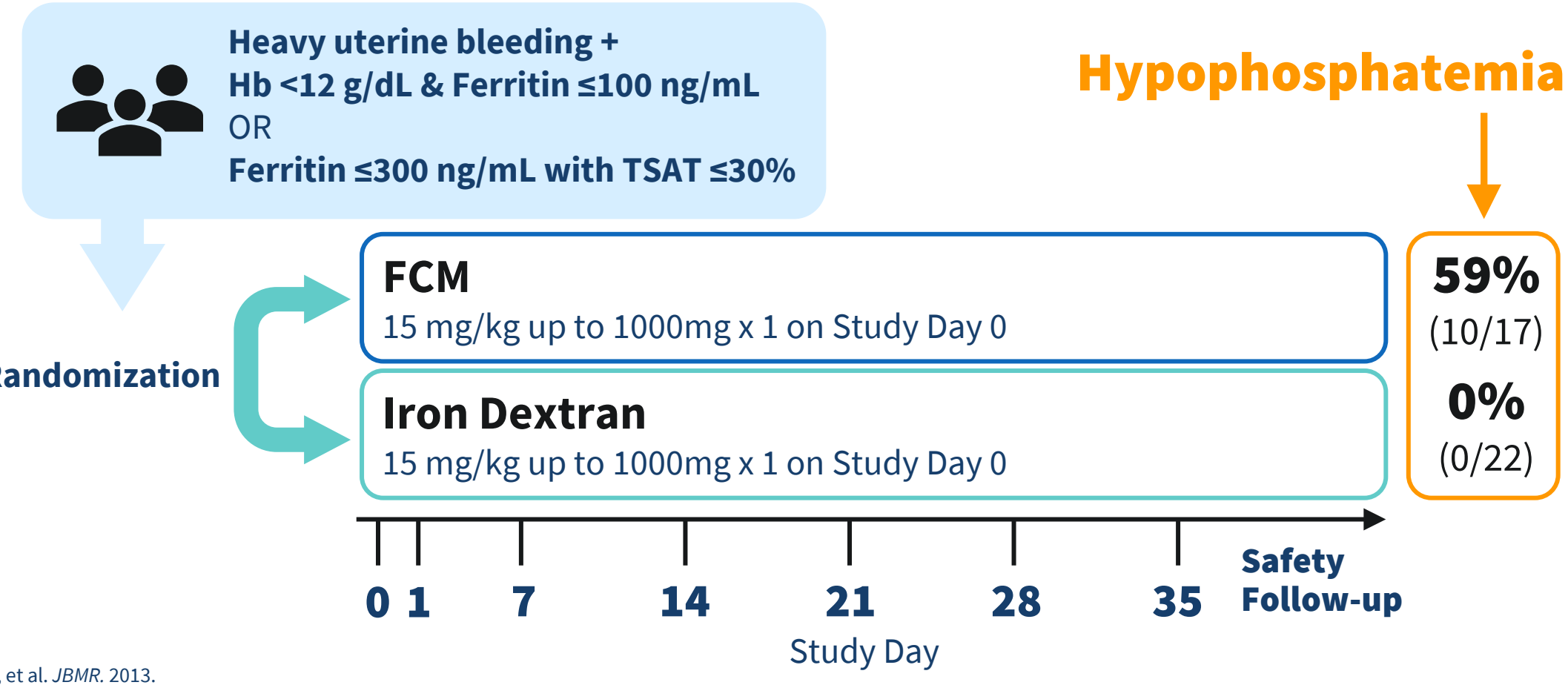
Fibroblast Growth Factor 23 (FGF23)

- Increased levels of intact FGF23 (iFGF23) **promote hypophosphatemia** via:
  - Urinary phosphate wasting
  - Reduced dietary absorption of phosphate in the gut
  - Reductions in biologically active vitamin D



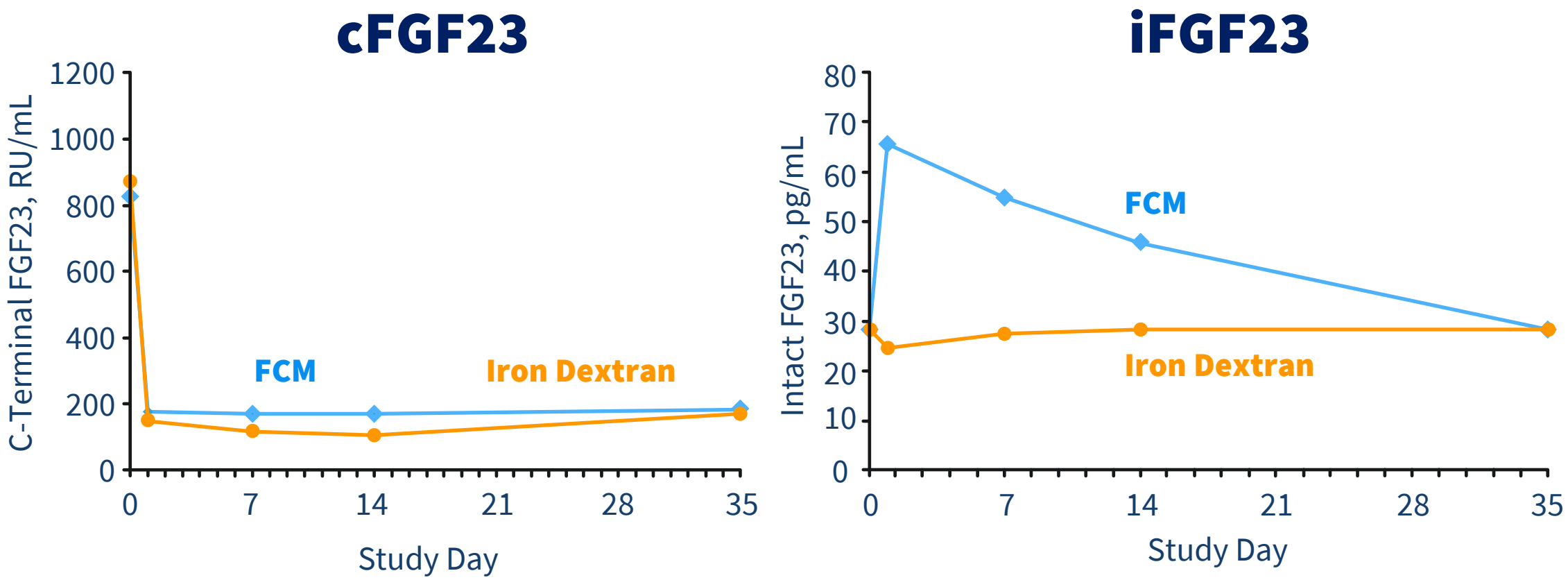
Kalantar-Zadeh K, et al. *Am J Hematol*. 2021.

FCM vs Iron Dextran



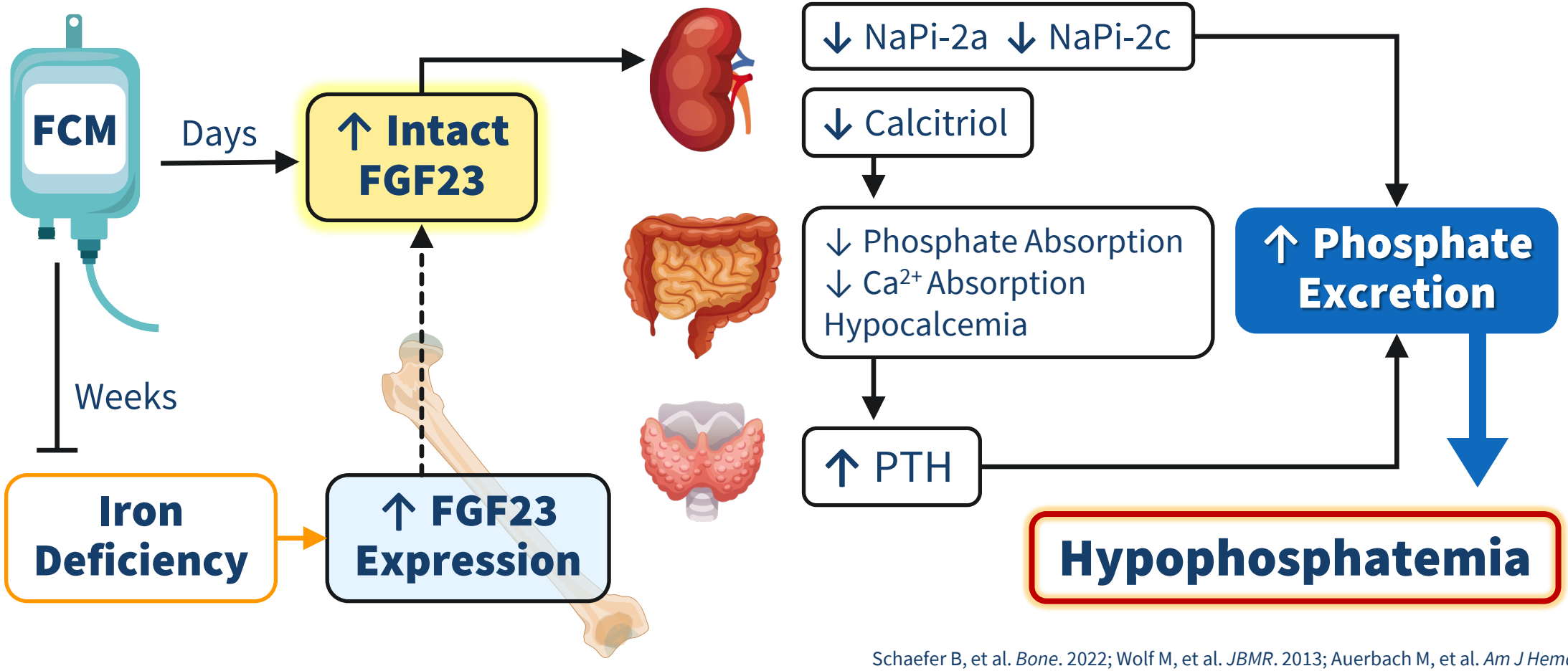
Wolf M, et al. *JBMR.* 2013.

Formative Differential in iFGF23 Levels



Wolf M, et al. *JBMR*. 2013.

Proposed Mechanism of FCM-Induced Hypophosphatemia

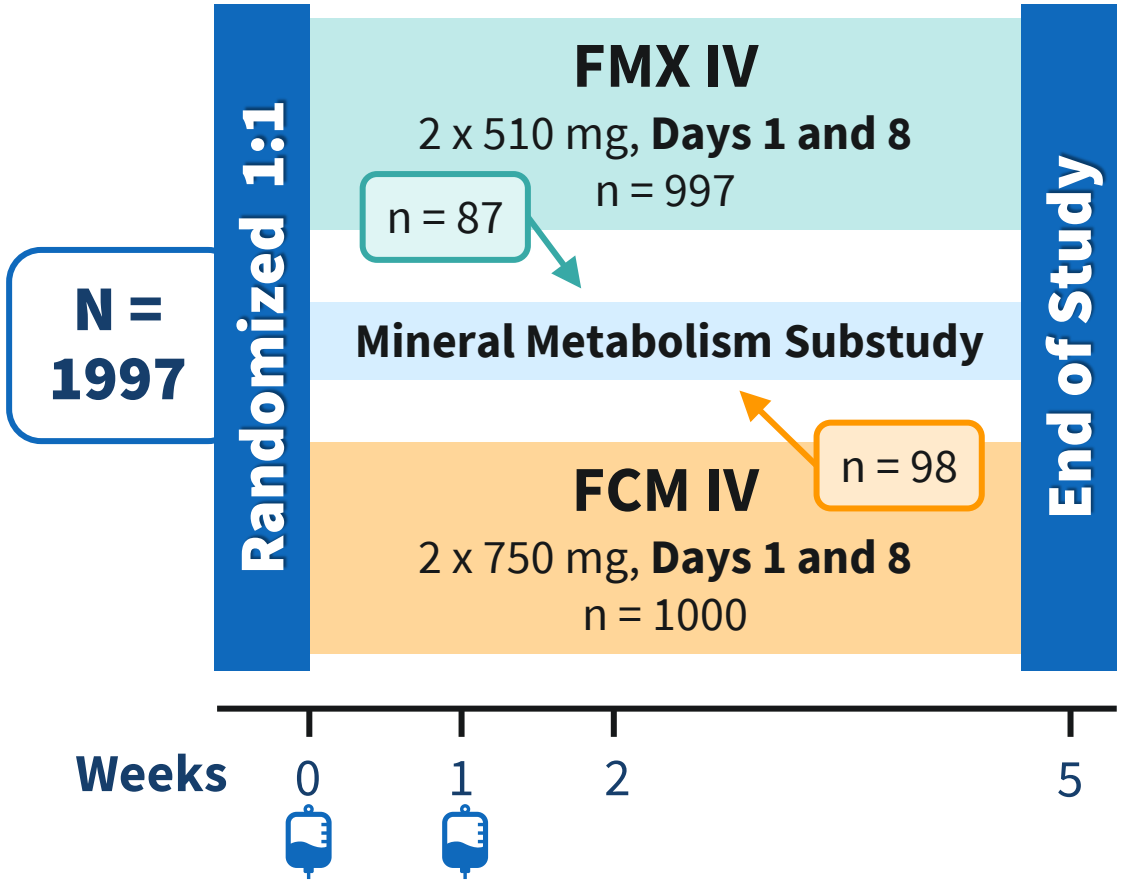


Schaefer B, et al. *Bone*. 2022; Wolf M, et al. *JBMR*. 2013; Auerbach M, et al. *Am J Hematol*. 2021.

The FIRM Trial

Multicenter, Double-Blinded RCT of Treatment of IDA of Diverse Causes

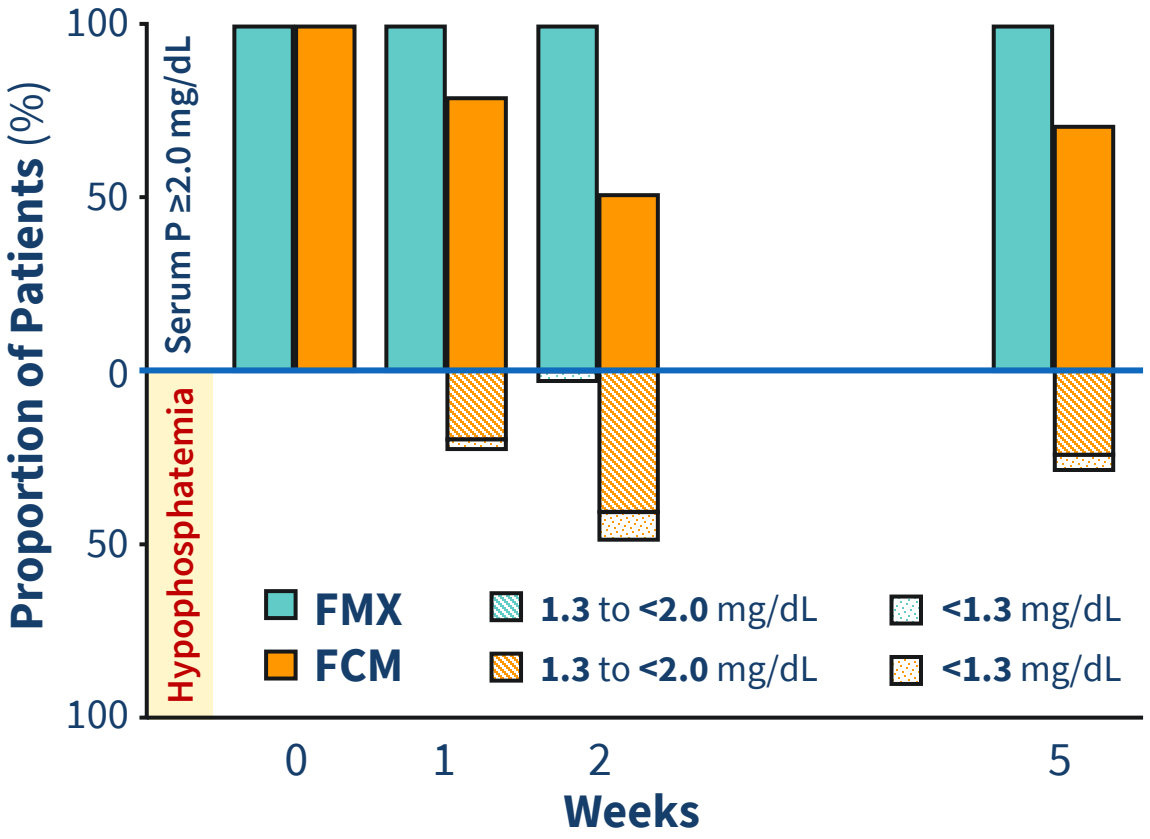
- **Key inclusion criteria**
  - Adults ≥18 years
  - **Women:** Hb <12.0 g/dL
  - **Men:** <14.0 g/dL
  - TSAT ≤20% or ferritin ≤100 ng/mL
  - Failed or did not tolerate oral Fe
- **Assays: weeks 0, 1, 2, 5**
  - Serum phosphate & fractional excretion of phosphate (FePi) in all
  - **Sub-study:**
    - cFGF23, iFGF23
    - 25D, 1,25D calcium, PTH

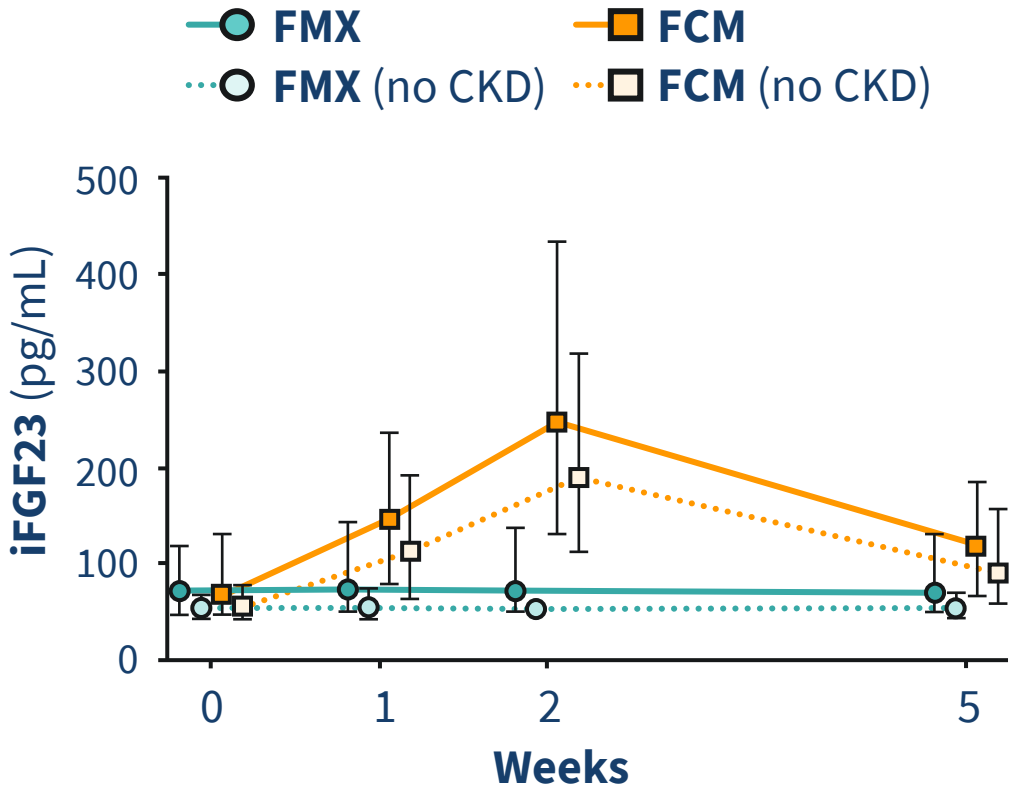


Wolf M, et al. *JCI Insight*. 2018

The FIRM Trial

Primary End Point: Serum Phosphate After IV Iron





Wolf M, et al. *JCI Insight*. 2018

Clinical Risk Factors for Incident and Persistent Hypo-P

Risk Factor	Incident Hypophosphatemia		Persistent Hypophosphatemia	
	Odds Ratio	**95% CI**	**Odds Ratio**	**95% CI**
FCM vs **FMX**	250.6	115.4-544.5	271.4	66.5-1-106.7
eGFR, per 10 mL/min/1.73 m^2 increase	1.07	1.01-1.13	-	-
Hb, per 1 g/dL increase	1.24	1.12-1.38	1.30	1.16-1.46
Weight, per 10 kg increase	0.92	0.87-0.97	0.79	0.73-0.86
Serum phosphate, per 1 mg/dL increase	0.31	0.23-0.41	0.24	0.17-0.34
Etiology of IDA				
Uterine bleeding vs other/unknown	1.81	1.18-2.76	-	-
CKD vs other/unknown	0.38	0.22-0.64	0.35	0.20-0.62
Black vs **White race**	-	-	1.87	1.26-2.79

Wolf M, et al. *JCI Insight*. 2018

The PHOSPHARE IDA Trials (A&B)

Study Design

- Two identically designed trials
- Adults >18 years with IDA, defined as hemoglobin (Hb) ≤11 g/dL, ferritin ≤100 ng/mL, eGFR ≥65 mL/min/1.73 m2, serum phosphate >2.5 mg/dL
- **1:1 randomized patients to receive:**
  - Iron isomaltoside (**IIM**) 1000/**FDI**: single infusion of 1,000 mg on Day 0; **or**
  - **FCM**: FDA-approved dosing schedule: 750 mg on Day 0 & Day 7
- **Overall:**
  - IIM/FDI: n = 125
  - FCM: n = 117
- Collected blood, urine at Days 0, 1, 7, 8, 14, 21, and 35
- **Primary endpoint:** incidence of hypophosphatemia <2.0 mg/dL (<0.65 mmol/L)
- **Other endpoints:** IDA markers, mineral metabolites, safety

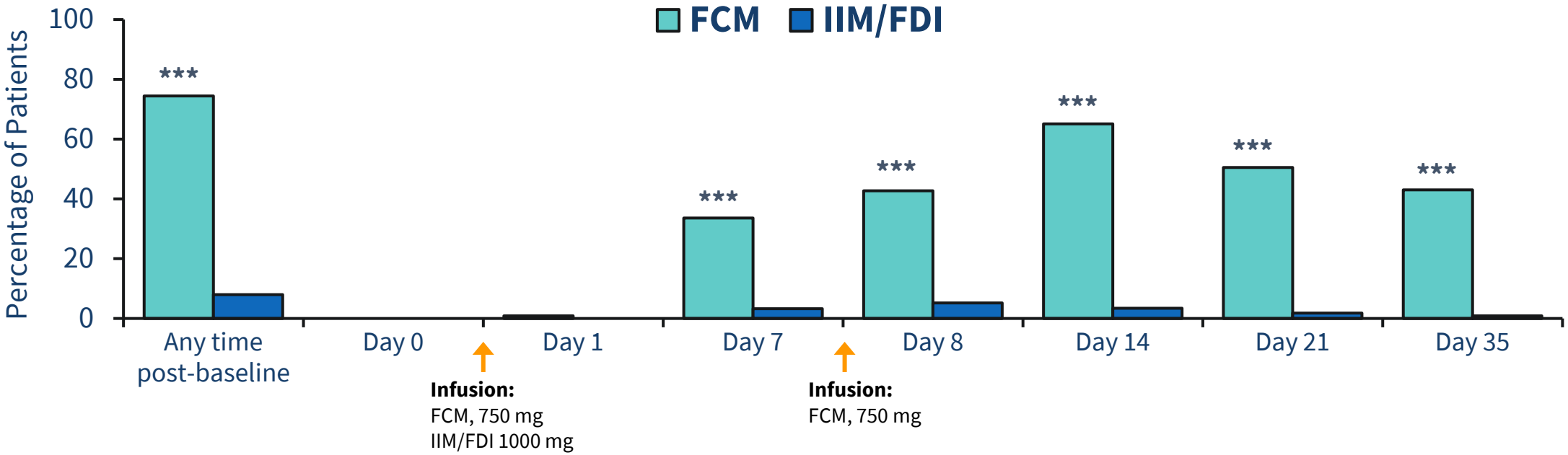
Wolf M, et al. *JAMA*. 2020.

The PHOSPHARE IDA Trials (A&B)

Primary Endpoint: FCM vs. FDI

Incidence of **hypophosphatemia <2 mg/dL**:
IIM/FDI: **8.0%** vs FCM: **74.4%**
***P*<0.001**

Incidence of **severe hypophosphatemia ≤1.0 mg/dL**:
IIM/FDI: **0.0%** vs FCM: **11.3%**
***P*<0.001**

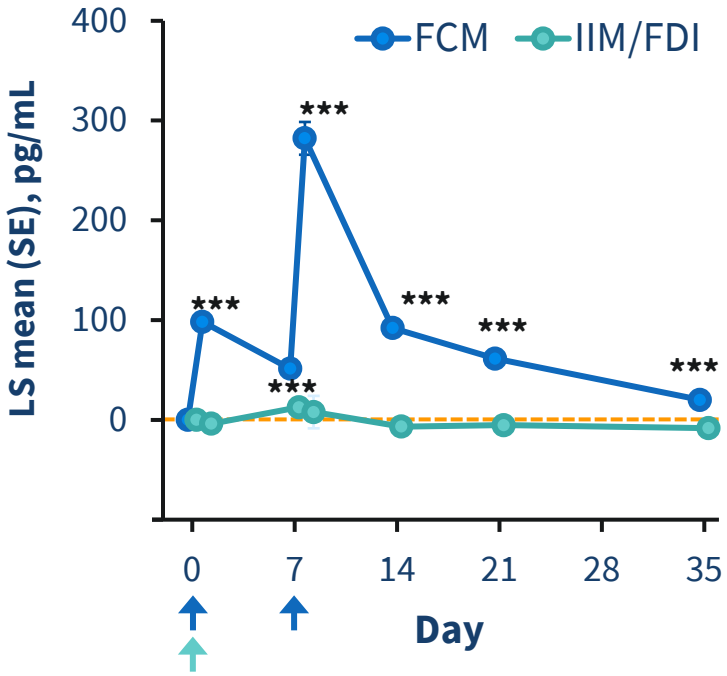


Wolf M, et al. *JAMA*. 2020.

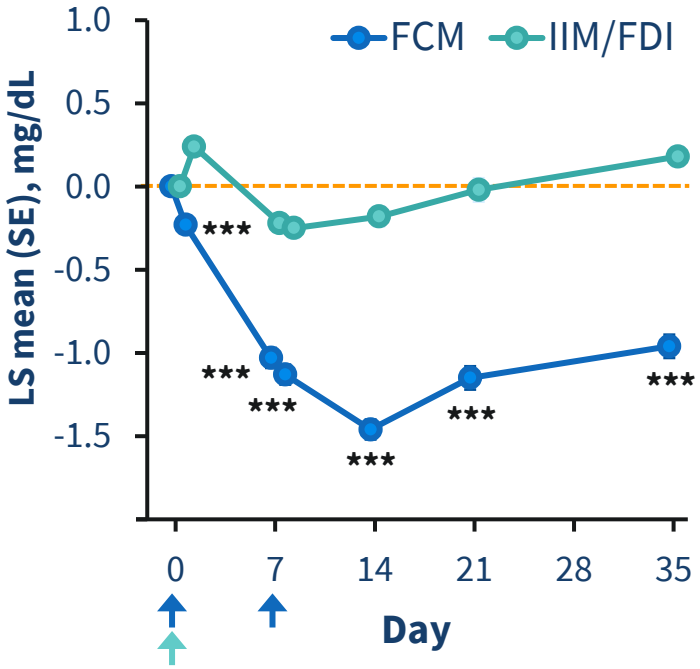
The PHOSPHARE IDA Trials (A&B)

Effects on iFGF23 & Phosphate: FCM vs. FDI

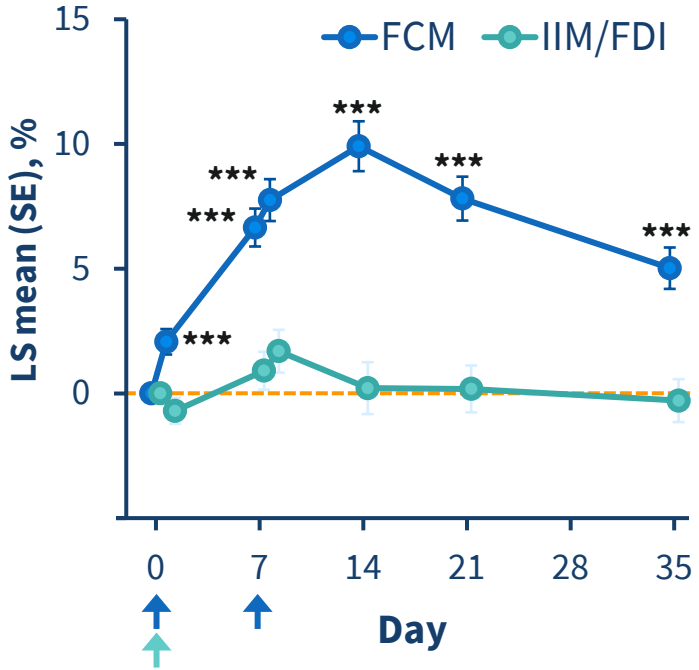
Intact FGF23



Serum Phosphate



Urinary Fractional Excretion of Phosphate

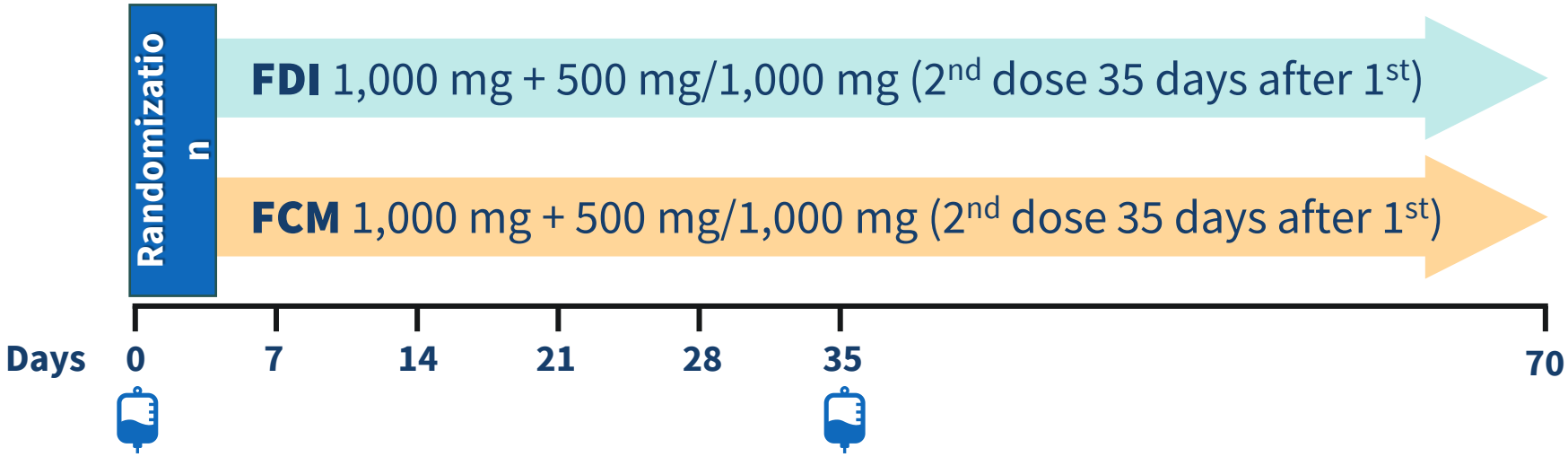


Wolf M, et al. *JAMA*. 2020.

The PHOSPHARE-IBD Trial

Study Design

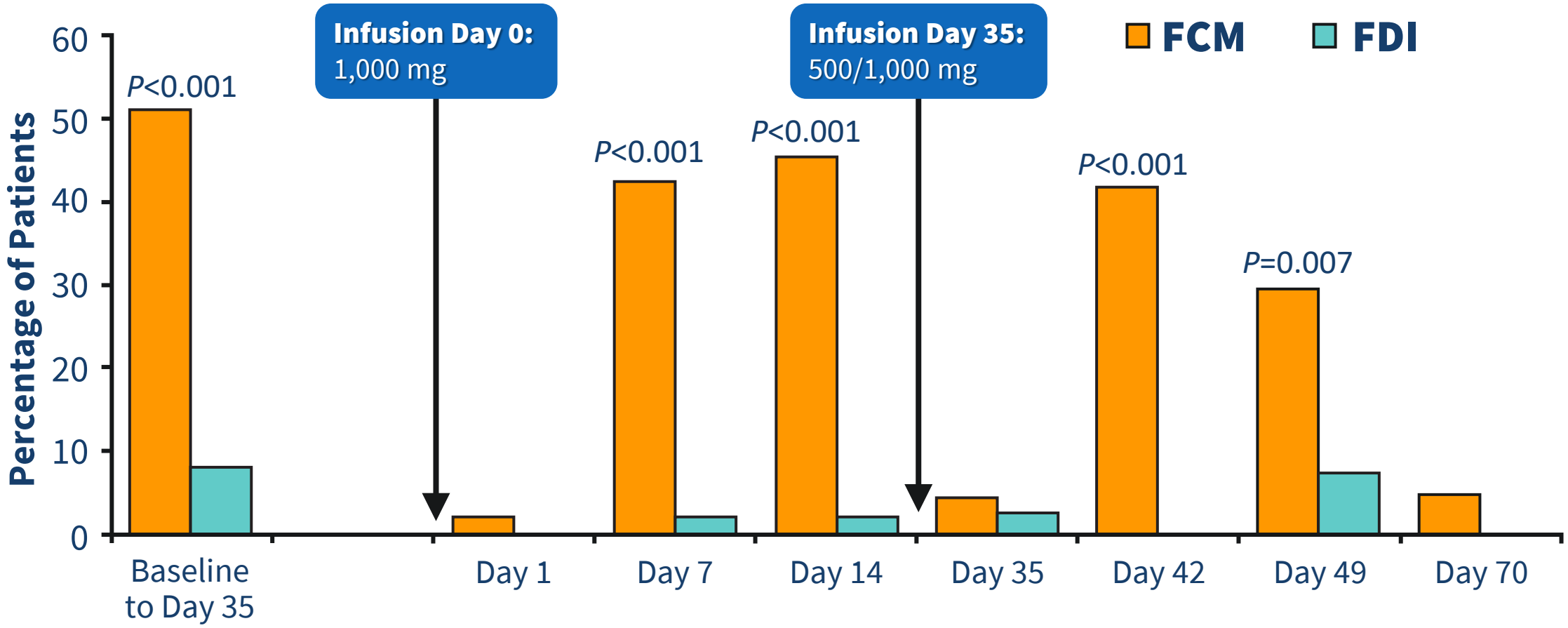
- Double-blinded RCT of **FDI vs FCM**
- **Inclusion:** Adults >18 years with IDA due to IBD, Hb ≤13 g/dL, ferritin ≤100 ng/mL, serum phosphate >2.5 mg/dL, weight >50 kg; **failed oral iron**
- **Required >1000 mg IV iron:** dosing on **Day 0** (1000) & **Day 35** (500-1000)
- **Primary outcome:** Incident hypophosphatemia



Zoller H, et al. *Gut*. 2023.

The PHOSPHARE-IBD Trial

Primary Outcome: Incident Hypophosphatemia

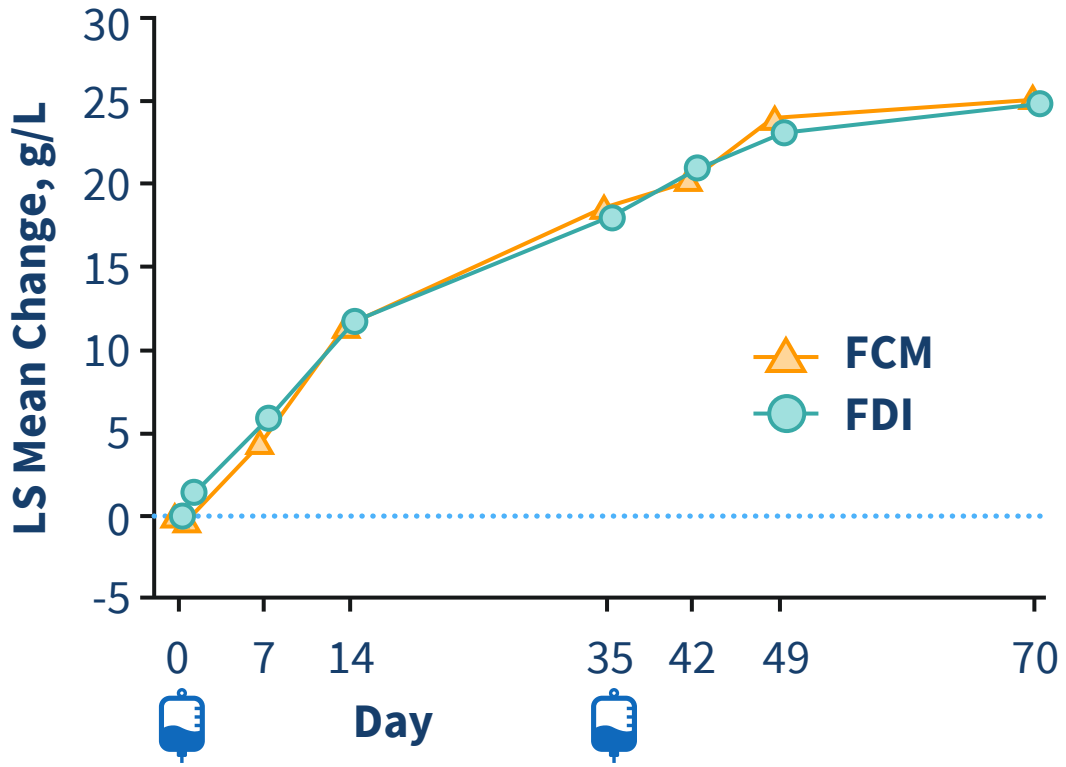


Zoller H, et al. *Gut*. 2023.

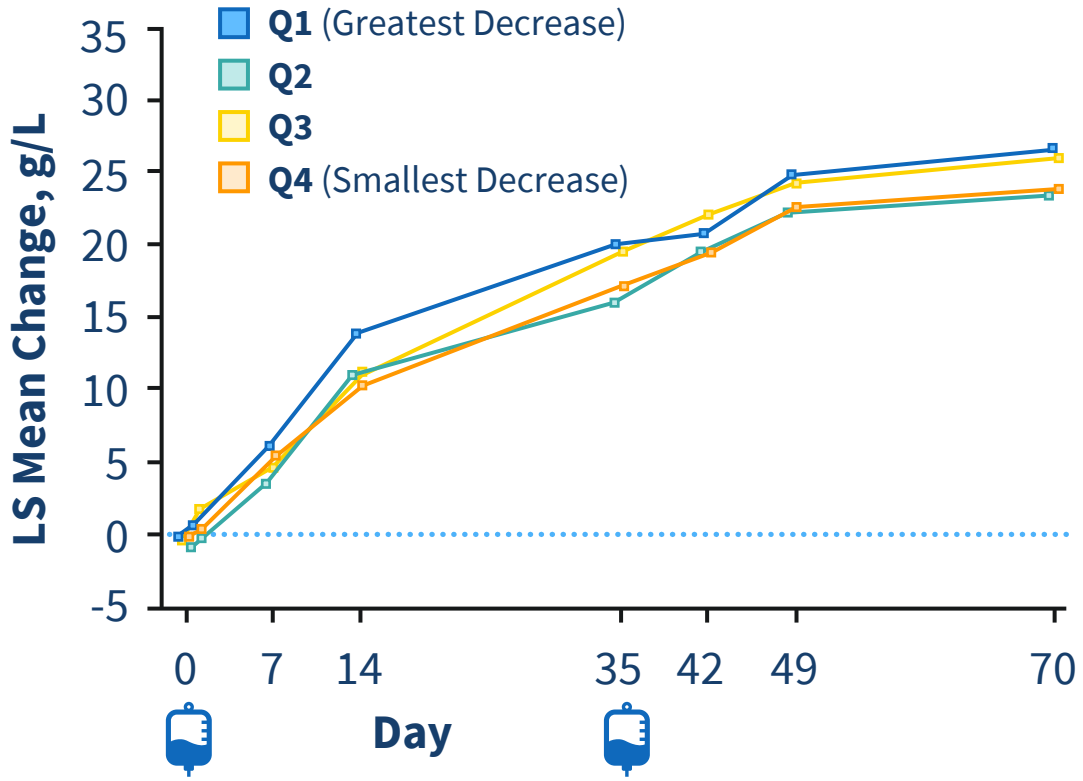
The PHOSPHARE-IBD Trial

Secondary Outcome: Hb

Hb



Hb Response by Decrease in Phosphate

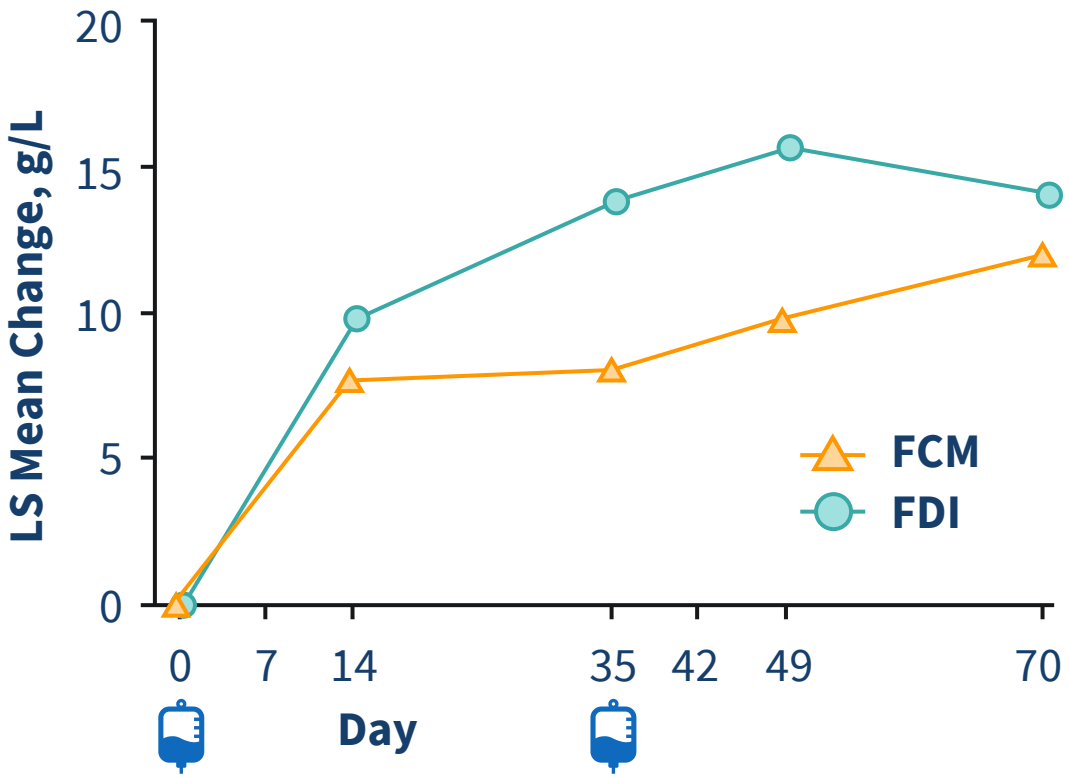


Zoller H, et al. *Gut*. 2023.

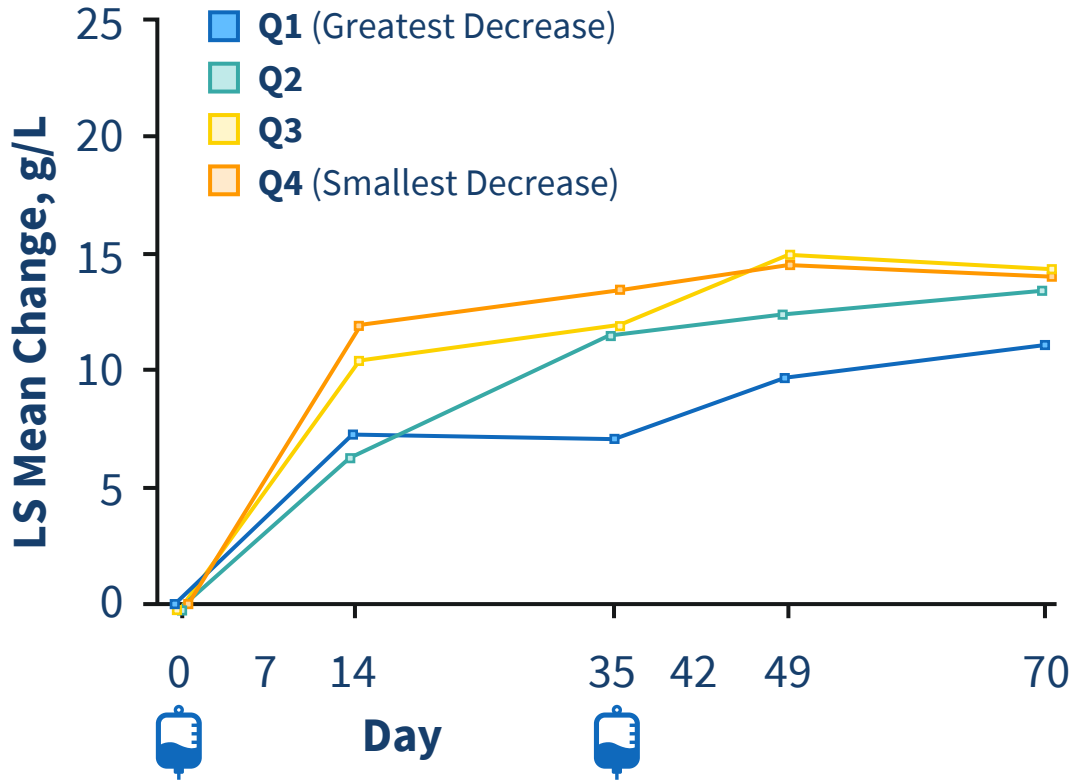
The PHOSPHARE-IBD Trial

Secondary Outcome: Fatigue

FACIT Fatigue Scale Score



FACIT Fatigue Scale Score by Decrease in Phosphate

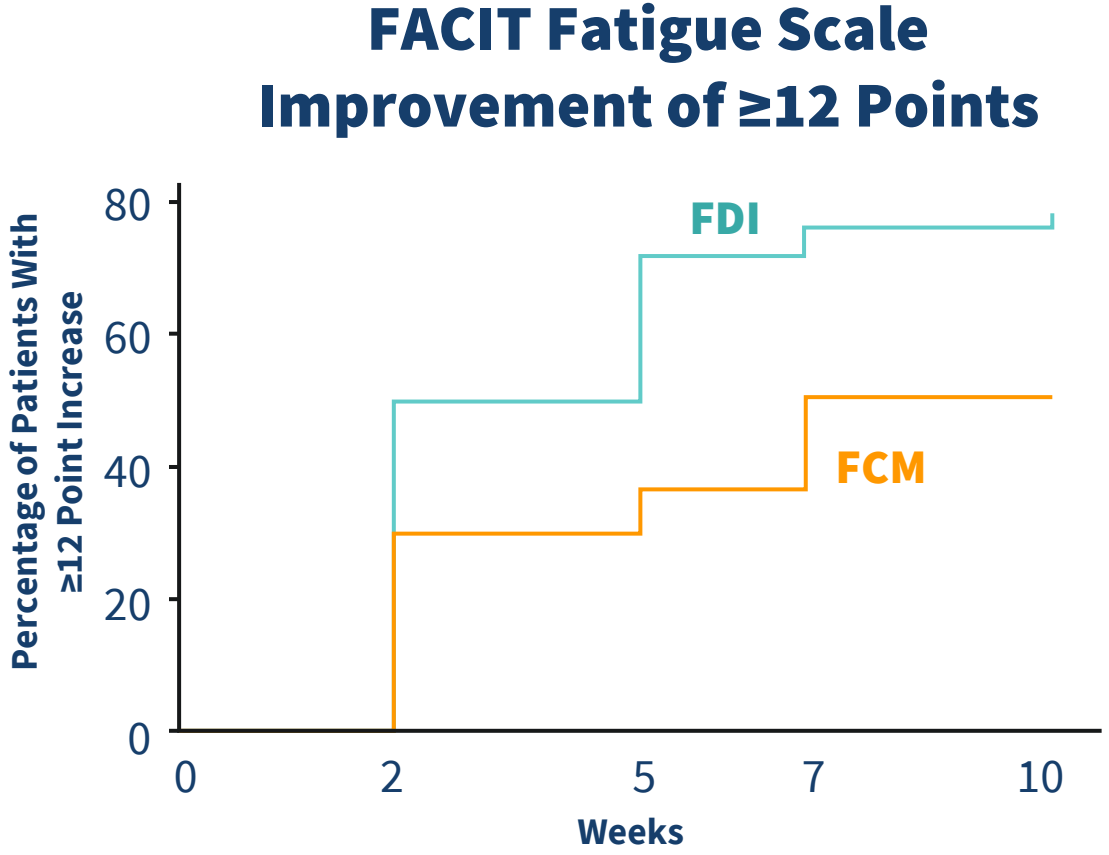


Zoller H, et al. *Gut*. 2023.

The PHOSPHARE-IBD Trial

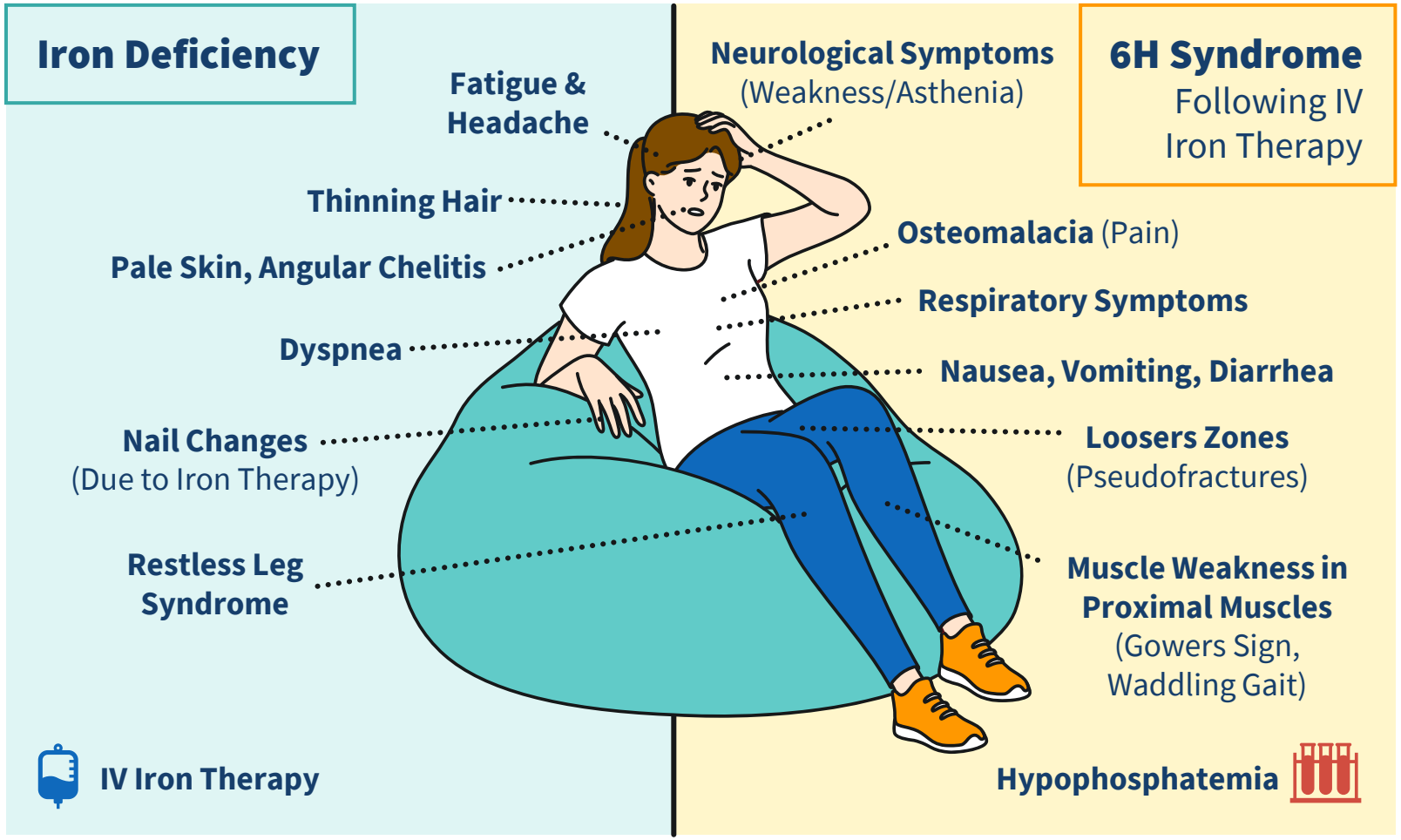
Fatigue Subanalysis: Is Hypo-P the Key?

- Percent of patients achieving a **FACIT fatigue scale improvement of ≥12 points** at any time during study period:
  - FDI = 78.3% **(*P*=0.005)**
  - FCM = 48.9%
- **Patients on FDI** were statistically significantly (*P*=0.003) **more likely to achieve FACIT scale fatigue improvements of ≥ 12 points** vs. patients on FCM



Zoller H, et al. *Gut*. 2023; Mehta AR, et al. *Blood*. 2022.

Why Does Hypo-P Matter?



Pooled Analysis of Symptoms

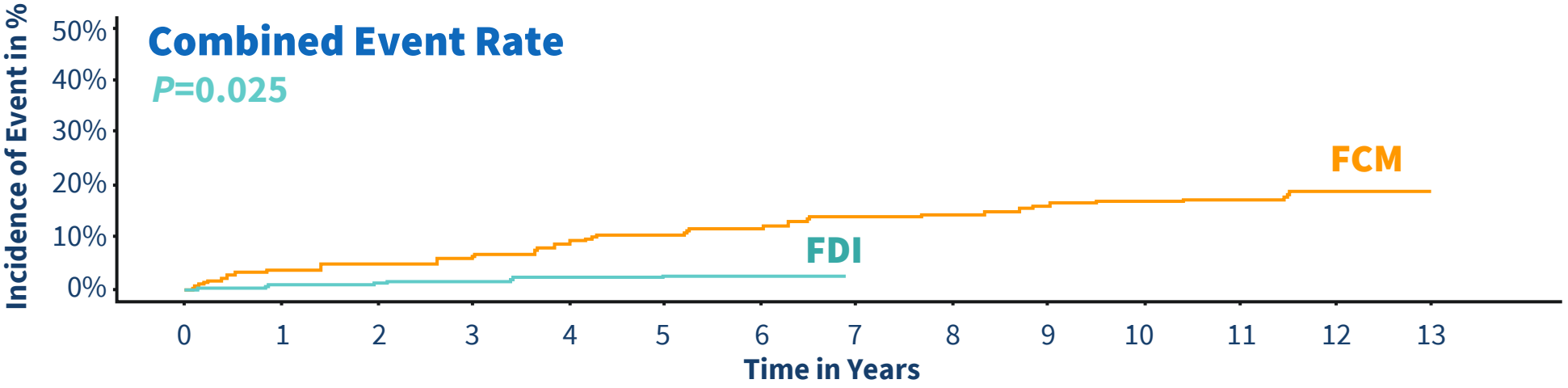
Symptoms/ Complications	Reported in [n]
General weakness/ asthenia	23/77
Bone pain	33/77
Muscle pain/weakness	20/77
Osteomalacia with fractures	34/77
Gait disturbance	14/77
Nausea/vomiting/ diarrhea	8/77
Neurological symptoms	10/77
Respiratory symptoms	3/77

Schaefer B, et al. *Bone*. 2021.

FCM-Associated Fractures? A Closer Look

- Retrospective analysis of 289 patients
  - Median follow-up: 5.8 years – FCM vs. FDI
- Evaluated **combined event rate** of:
  - Fractures
  - Radiological signs of osteomalacia
  - Kidney stones

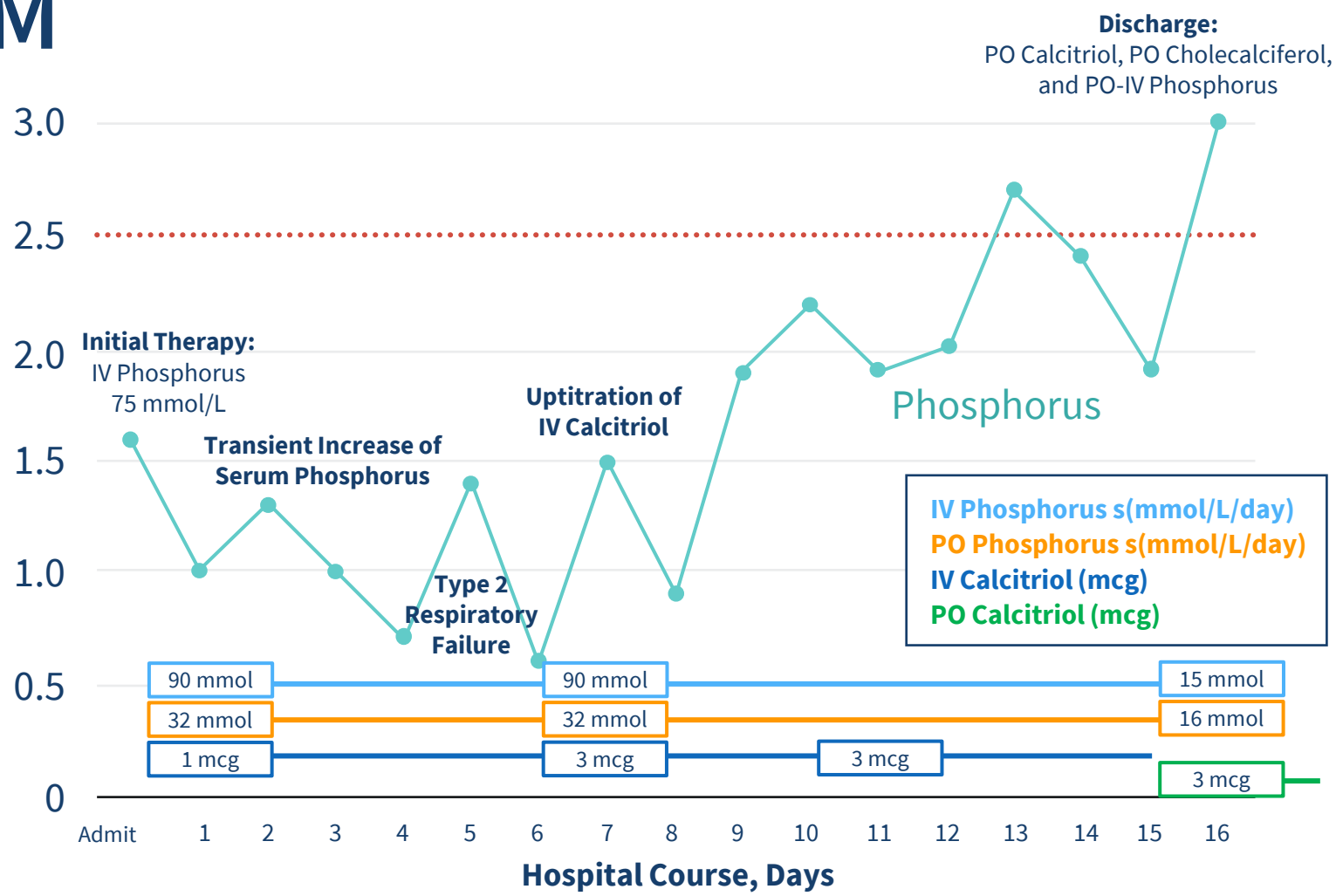
- Combined event rate was **significantly higher with FCM** vs. FDI (*P*=0.025)
- Specific to **fracture risk**, the **HR for FCM was 4.54 relative to FDI** (*P*=0.04)



Zoller H, et al. *ASH*. 2023. Poster #3838; Schaefer B, et al. *Bone*. 2021; Schaefer B, et al. *Br J Clin Pharmacol*. 2021.

Severe Hypophosphatemia After 1 Course of FCM

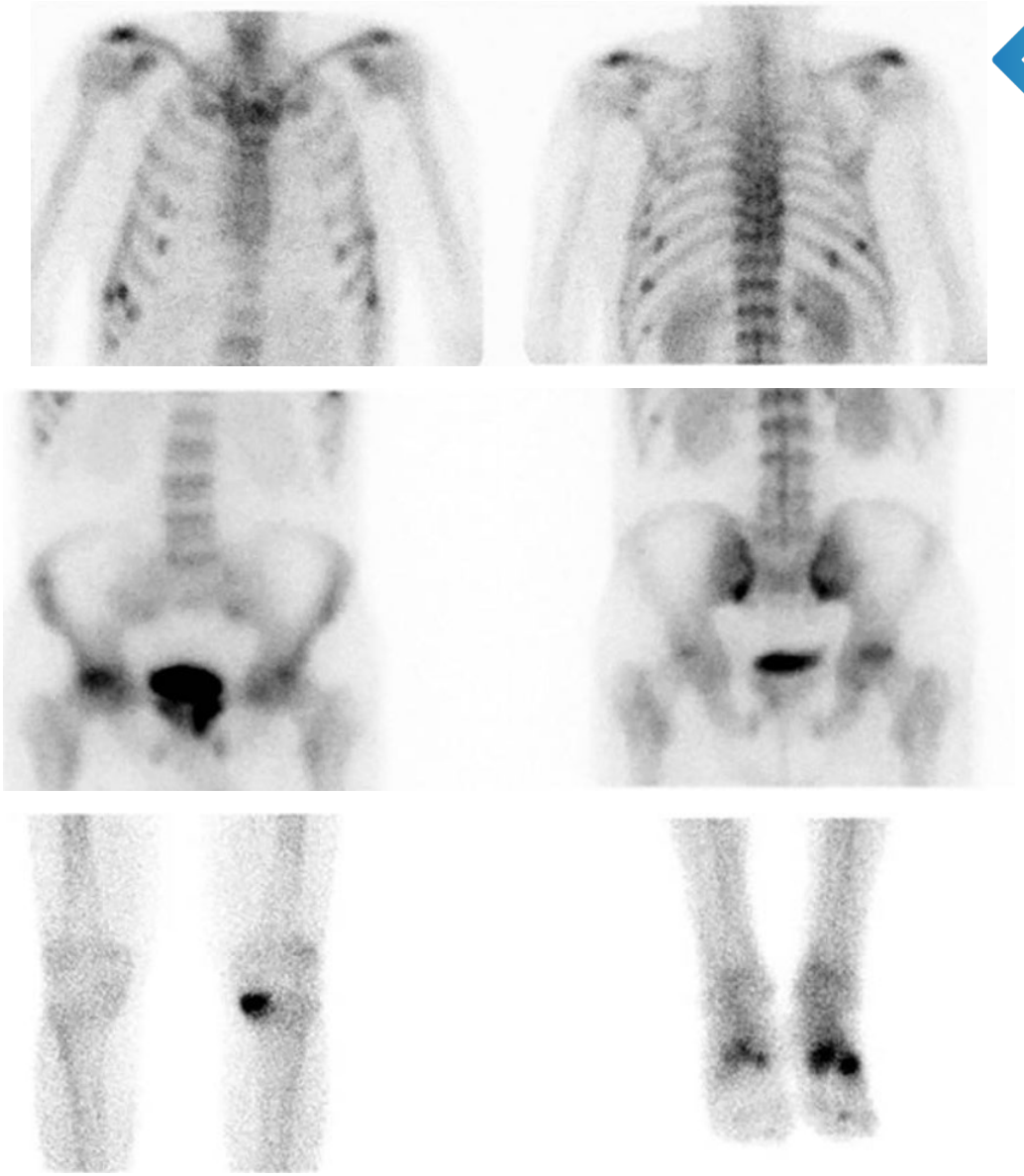
- 28-year-old woman
- Fatigue, muscle weakness, palpitations 2 weeks PTA
- Uterine bleeding → IDA
- FCM, 750mg x 2 doses 8 weeks PTA
- Presented with: hypophosphatemia, renal phosphate wasting
- Rx: PO, IV phosphate; 1,25D
- **Acute respiratory failure on day 7: serum phosphate 0.6**



Vasquez-Rios G, et al. *Nefrologia.* 2021.

Real-World Impact of FCM-Induced Hypo-P in HHT

- 65-year-old man with HHT
- Monthly FCM infusions x 2 years
- Reported chronic, progressive bone pain, worsened by movement
- Labs
  - **Phosphate:** 1.2 mg/dL
  - **C-terminal FGF23:** >3x ULN
- **Diagnosis:** FGF23-mediated hypophosphatemic osteomalacia with diffuse insufficiency fractures
- **Treatment:** PO phosphate supplementation, PO calcium/vitamin D, switched FCM to iron sucrose
- **Clinical Outcome:** pain and mobility limitations resolved; labs normalized



Callejas-Moraga EL, et al. *Bone Rep*. 2020.

Managing IV Iron-Induced Hypo-P

Iron deficiency with impaired absorption or intolerance/ inadequate response to oral iron

- Evaluate/correct underlying etiology
- Start IV iron repletion therapy

Any of the following risk factors present?

- Severe iron deficiency (ferritin <10 ng/mL)
- Lower body weight
- Lower baseline serum phosphate level
- Abnormal uterine bleeding
- Need for repeat doses of IV iron

NO → Assess institution-specific resources and IV iron formulation availability

YES → Avoid IV FCM if alternate formulations available

Assess institution-specific resources and IV iron formulation availability → Non-FCM formulation available?

NO → Repeat serum phosphate at day 7 prior to second infusion

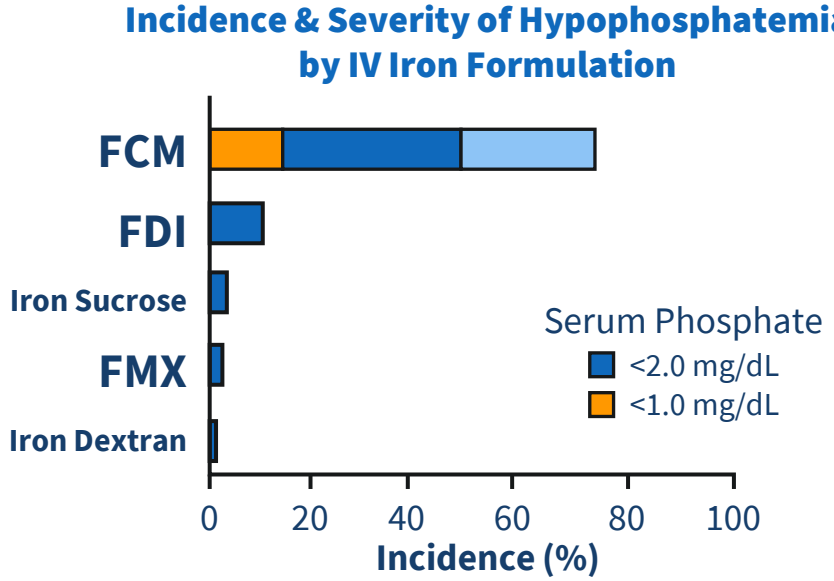
- **Phosphate >2.0 mg/dL** → **Proceed with 2nd infusion of IV FCM**
- **Phosphate ≤2.0 mg/dL** → **Avoid 2nd dose**; Management based on symptoms and severity of hypophosphatemia

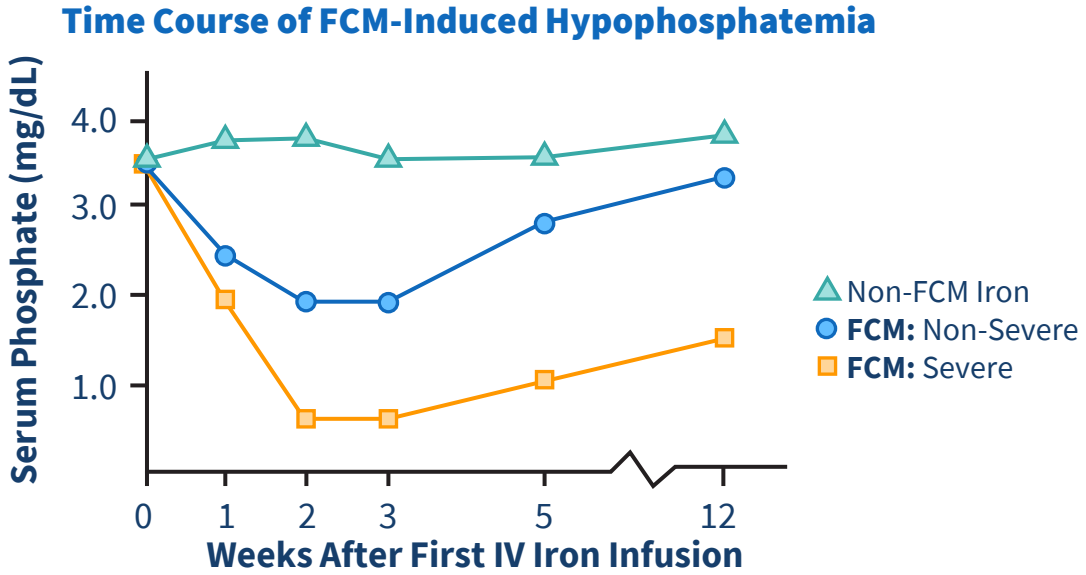
YES → Avoid IV FCM if alternate formulations available

Martens KL, Wolf M. *Am Soc Hematol*. 2023.

Summary

- **HHT patients are at an elevated risk for IV iron-induced hypophosphatemia because of repeated, longitudinal infusion needs**
- This risk is greatest with FCM
- IV iron-induced hypophosphatemia is **challenging to diagnose and treat**
  - Overlapping signs and symptoms with ID/IDA: fatigue, asthenia, lethargy, weakness, dyspnea
- Key Points in Management
  - Repletion strategies are ineffective due to renal leak
  - Repletion strategies stimulate FGF23 → worsens leak
  - **Primary prevention is best approach**



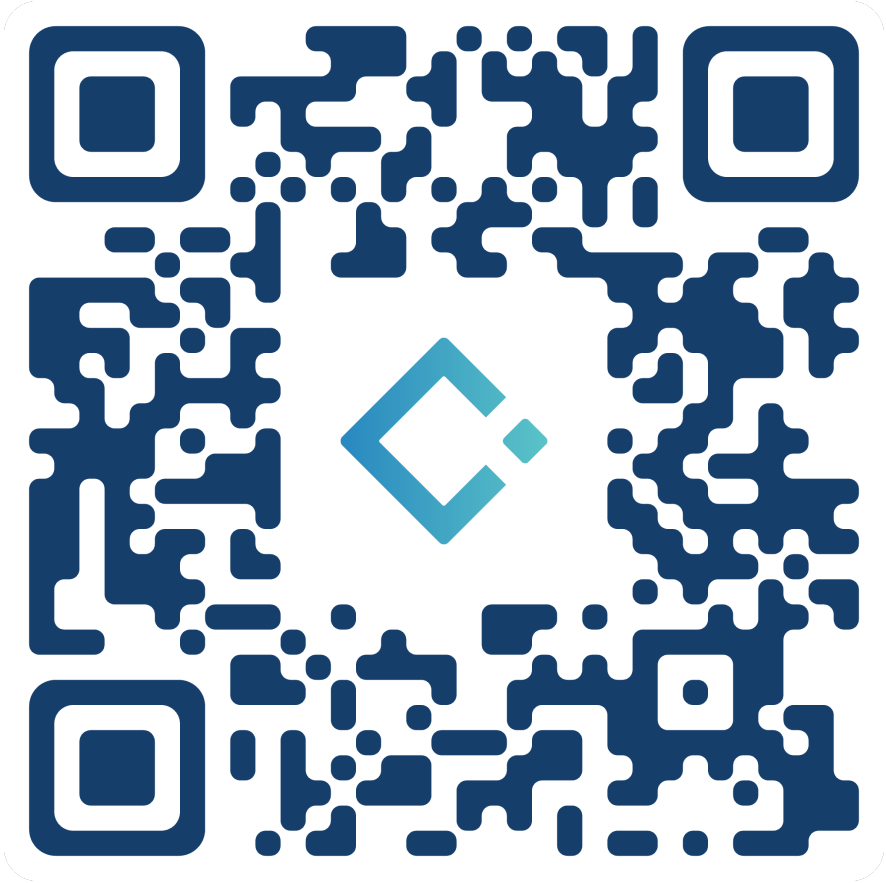


Martens KL, Wolf M. *Am Soc Hematol.* 2023.

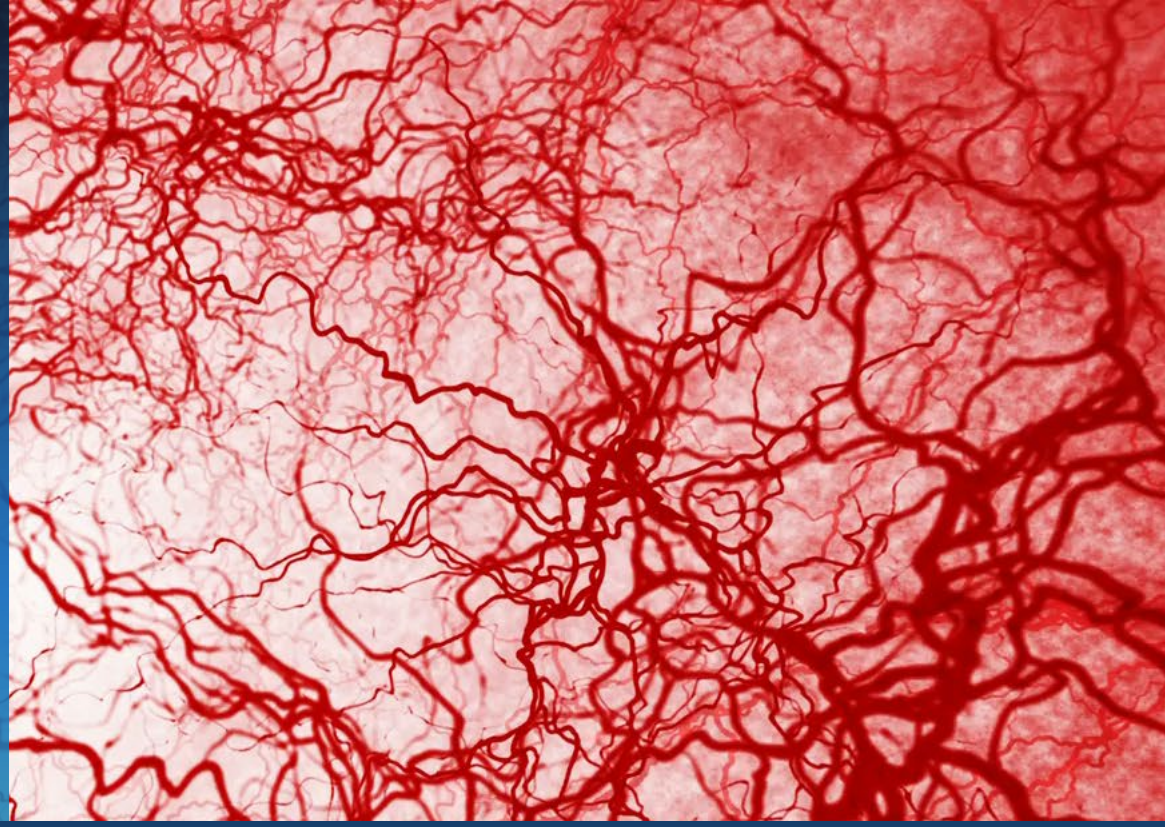
Jack's Case Conclusion

- Jack is diagnosed with IV iron-induced hypophosphatemic fractures
- You start oral phosphate, daily calcium + vit D tablet; his bevacizumab therapy is continued
- **You discontinue FCM and begin FDI 1,000 mg given over at least 20 minutes**
- After labs normalize and fractures heal, Jack returns to work and **continues IV FDI infusions every 4 months** for long term management of his HHT-associated IDA

Post-Test and Activity Evaluation



Closing Chasms and Optimizing Care in Hereditary Hemorrhagic Telangiectasia:



Expert Perspectives on the Role of Intravenous Iron in the Management of HHT-Associated IDA

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