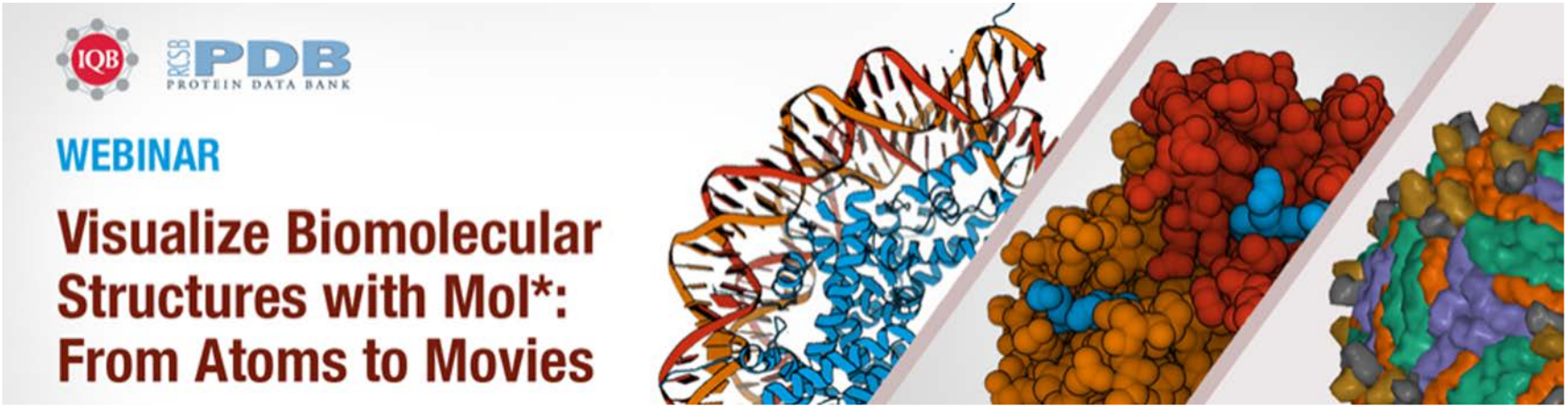



Shuchismita Dutta, Ph.D.

*Scientific Training, Education, and Documentation Lead*
*RCSB Protein Data Bank*

February 13, 2024

# Agenda

- The Storyline
- The Tool
- Visualizing Molecular Stories

FDA NEWS RELEASE

## FDA Approves First Gene Therapies to Treat Patients with Sickle Cell Disease

Share | Post | Linkedin | Email | Print

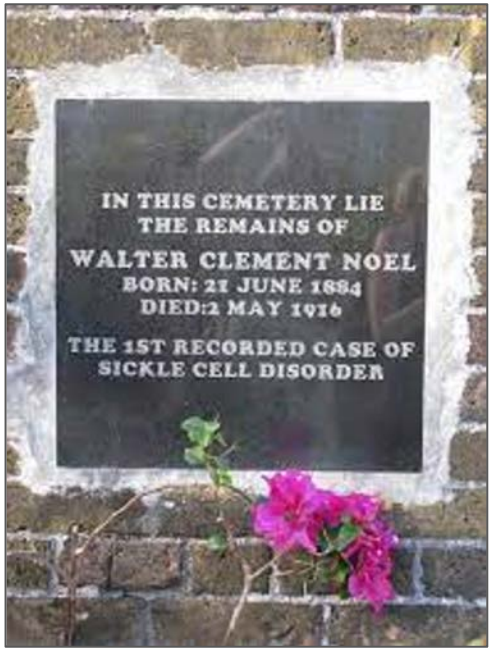
**For Immediate Release:** December 08, 2023

Today, the U.S. Food and Drug Administration approved two milestone treatments, Casgevy and Lyfgenia, representing the first cell-based gene therapies for the treatment of sickle cell disease (SCD) in patients 12 years and older. Additionally, one of these therapies, Casgevy, is the first FDA-approved treatment to utilize a type of novel genome editing technology, signaling an innovative advancement in the field of gene therapy.

https://www.fda.gov/news-events/press-announcements/fda-approves-first-gene-therapies-treat-patients-sickle-cell-disease

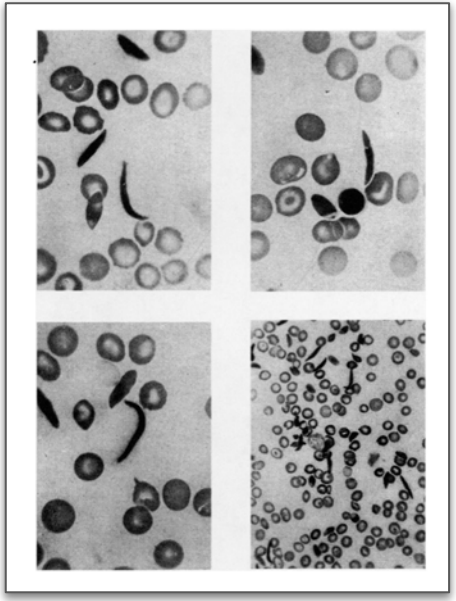
# Agenda

- The Storyline
- The Tool
- Visualizing Molecular Stories



# A Timeline for Sickle Cell Disease - 1

- **1910**: James Herrick published a report describing the first documented case of Sickle Cell Anemia
- **1949**: James Van Neel figured out inheritance of Sickle cell disease (SCD)
- **1949**: Linus Pauling described SCD as the first molecular disease



Herrick JB. Peculiar elongated and sickle-shaped red blood corpuscles in a case of severe anemia. 1910. *The Yale Journal of Biology and Medicine*. 2001;74(3):179-184.

64 SCIENCE July 15, 1949, Vol. 110

The Inheritance of Sickle Cell Anemia[1]

James V. Neel

*Heredity Clinic, Laboratory of Vertebrate Biology, University of Michigan, Ann*

November 25, 1949, Vol. 110 SCIENCE 543

Sickle Cell Anemia, a Molecular Disease[1]

Linus Pauling, Harvey A. Itano,[2] S. J. Singer,[2] and Ibert C. Wells[2]

*Gates and Crellin Laboratories of Chemistry,*
*California Institute of Technology, Pasadena, California*[4]

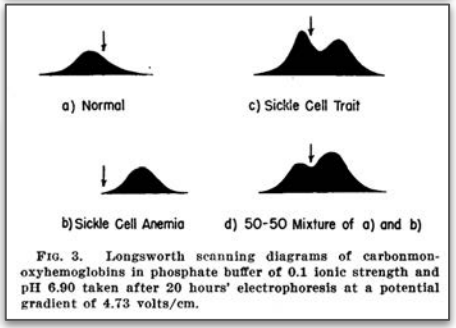
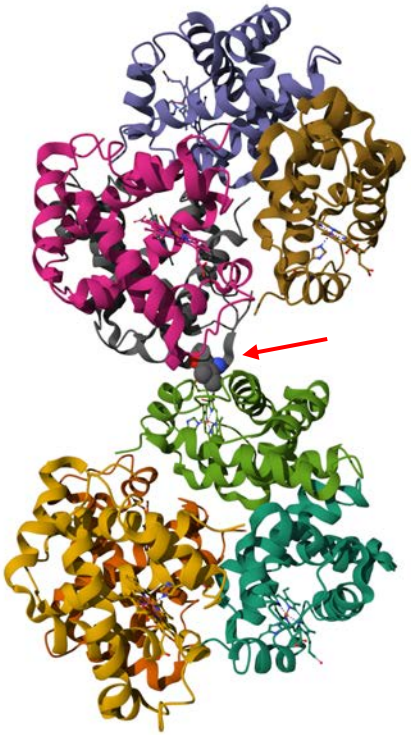



FIG. 3. Longsworth scanning diagrams of carbonmonoxyhemoglobins in phosphate buffer of 0.1 ionic strength and pH 6.90 taken after 20 hours' electrophoresis at a potential gradient of 4.73 volts/cm.

# A Timeline for Sickle Cell Disease -2

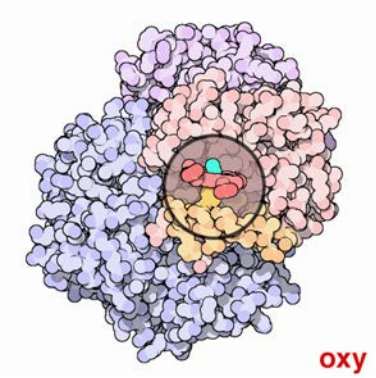
- **1950s**: Max Perutz solved the 3D structure of a series of Hemoglobin molecules, from various organisms, with and without oxygen/carbon monoxide etc.
- **1980s**: First structure of hemoglobin with the sickle cell mutation.

PDB 1hbs: Human deoxy Hb S



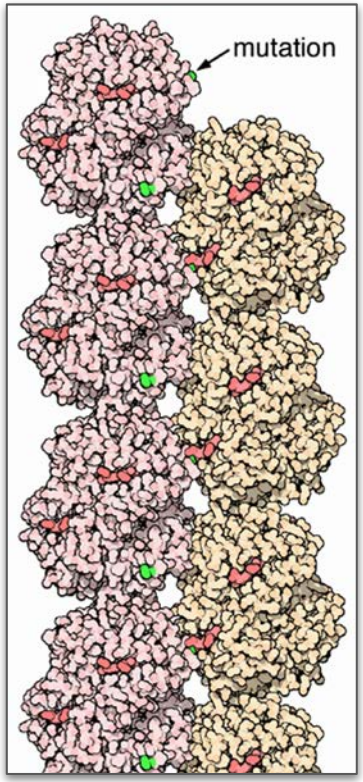
PDB 2dhb: Horse deoxy Hb

PDB 4hhb: Human deoxy Hb

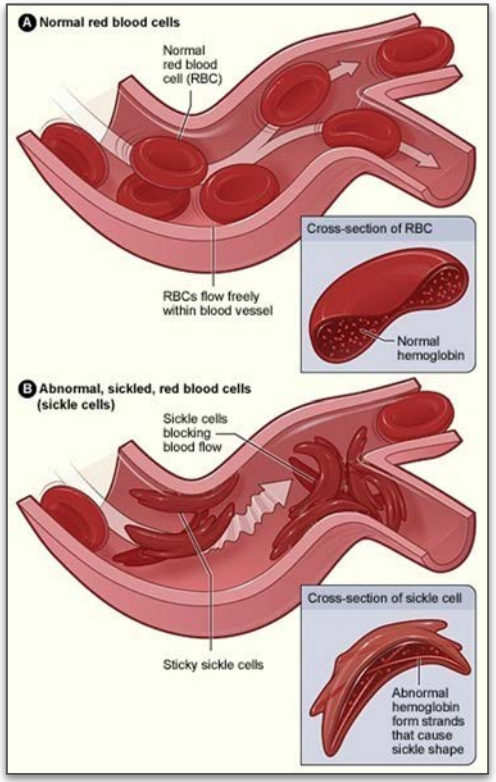


# Sickle Cell Disease Leads to

- Acute Chest Syndrome
- Anemia
- Blood Clots
- Hand-Foot Syndrome
- Infection
- Organ Damage (legs, kidneys)
- Pain
  - Chronic pain
  - Vaso-occlusive crisis (VOC)
- Pulmonary hypertension
- Stroke
- Vision loss



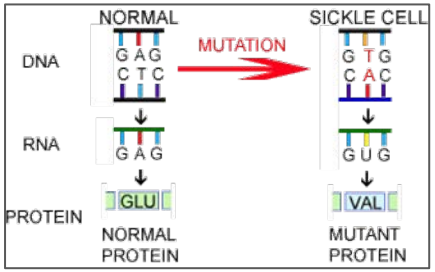

https://pdb101.rcsb.org/motm/41

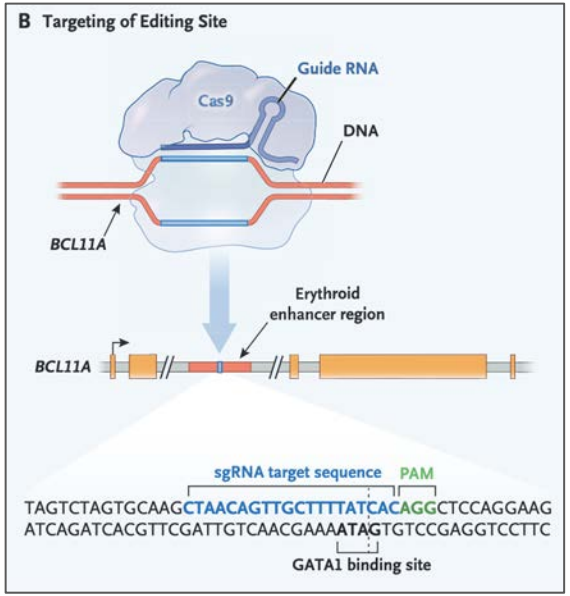



https://www.nhlbi.nih.gov/health/sickle-cell-disease/causes

# A Timeline for Sickle Cell Disease -3

- **1990s**: Inspired by mild cases of SCD in individuals with hereditary persistence of fetal hemoglobin (HPFH), research lead to US FDA approving use of Hydroxyurea to treat SCD
- **2000s**: Role of BCL11A TF repressor of gamma hemoglobin studied.
- **2010s**: Several approaches developed to prevent HbS polymerization, and reduction of aggregation of sickled RBCs to reduce pain during the Vaso Occlusive Episodes (VOEs).




Frangoul et al., 2021;
DOI: 10.1056/NEJMoa2031054

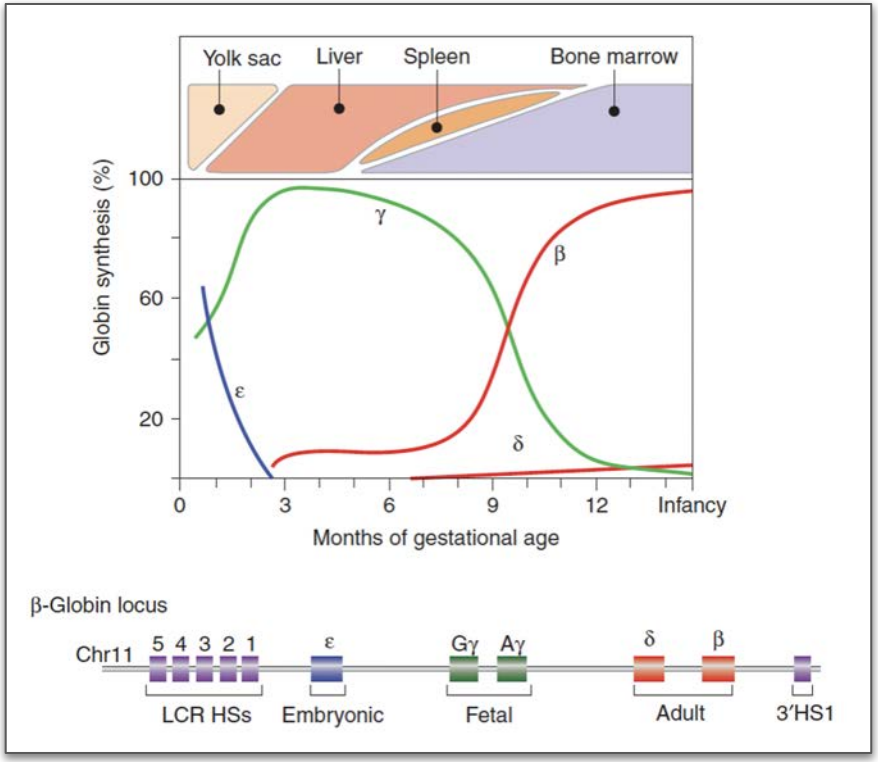
# Managing/Treating Sickle Cell Disease (SCD)

Diagnosis

- Blood test

Management

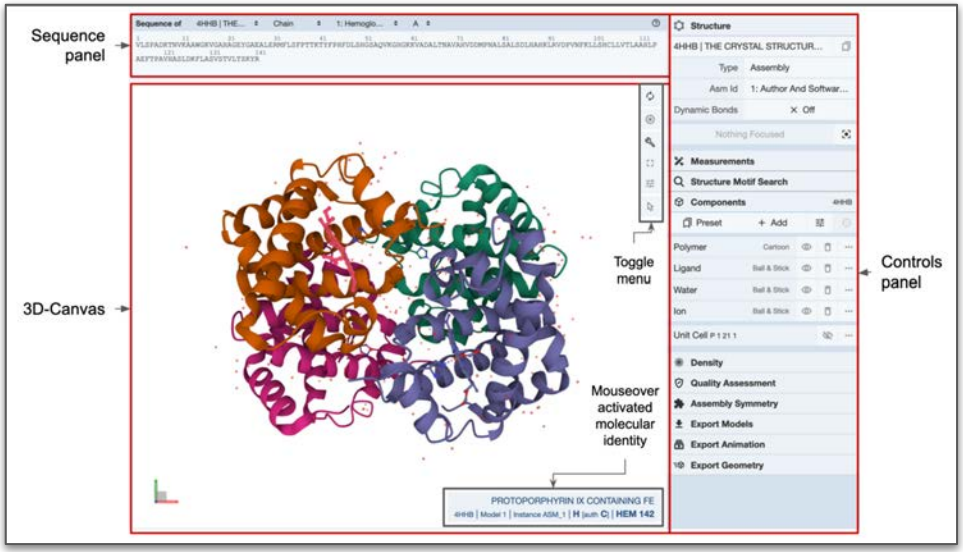
- Bone marrow transplant
- Medications
  - ***Hydroxyurea*** (oral medicine) activates erythroid progenitors to increase HbF production reducing complications of SCD
  - **Voxelotor** (oral medicine) prevents red blood cells from forming the sickle shape.
  - ***Crizanlizumab***-tmca is (IV medicine) prevents blood cells from sticking to blood vessel walls
- Gene therapy
  - **Lyfgenia** (cell-based) uses a lentiviral vector to introduce a modified antisickling HbAT87Q, that functions similarly to hemoglobin A.
  - **Casgevy** (cell-based) uses CRISPR/Cas9 to reduce BCL11a expression and increased γ-globin expression and HbF production




Sankaran & Orkin, 2013
https://doi.org/10.1101%2Fcshperspect.a011643

# Agenda

- The Storyline
- The Tool
  - Linked to a Structure Summary Page
    - File from RCSB.org
  - Standalone RCSB.org Mol*
    - File from local disc
    - File from another resource (url)
- Visualizing Molecular Stories



# What can you do with RCSB.org Mol*?

**Explore a biomolecular 3D structure**

- View the whole structure or parts
- Change representations, colors
- View Assembly; Experimental data/Validation; Symmetry
- Measure: length, angle, dihedrals
- Save images, animations

**Integrate information from other sources**

- View annotations mapped from UniProt, SCOP, CATH etc.

**Compare biomolecular 3D structures**

- Use various algorithms to compare structures
- View superposed polymer chains in 3D and see associated polymer and non-polymers components

**Explore trends/patterns in groups of structures**

- Group by Structure (Group ID) or Polymer sequence (UniProt ID or sequence similarity)
- Display superposed structures to see complete polymer, specific features, associated polymer and non-polymer components

# Agenda

- The Storyline
- The Tool
- Visualizing Molecular Stories (using Mol*)

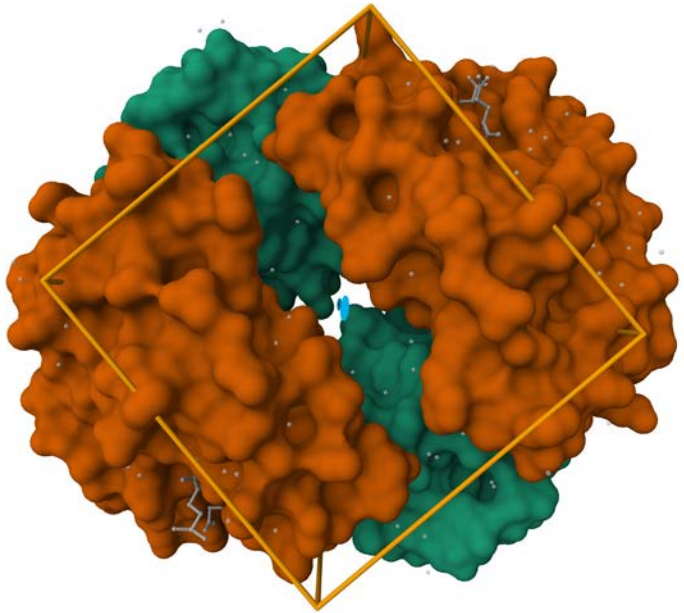
See Companion Document for PDB IDs and instructions

PDB ID 2hbs

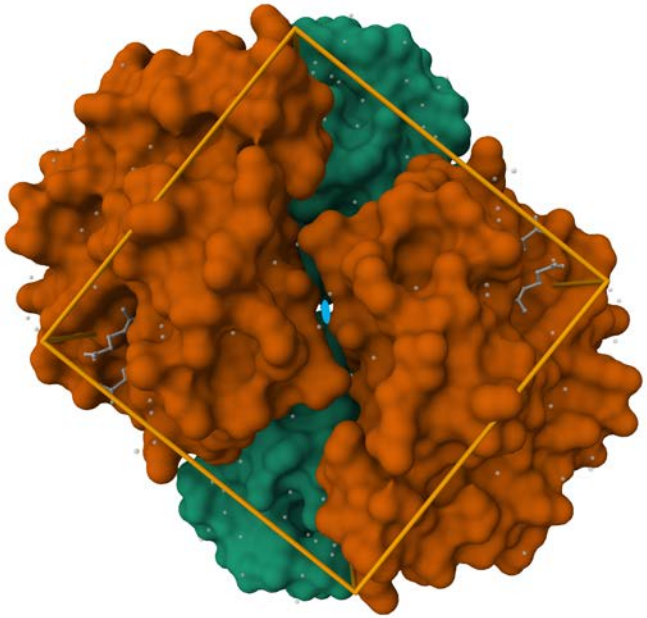
# Exploring Hemoglobin Structures

# Hemoglobin - Conformational Changes

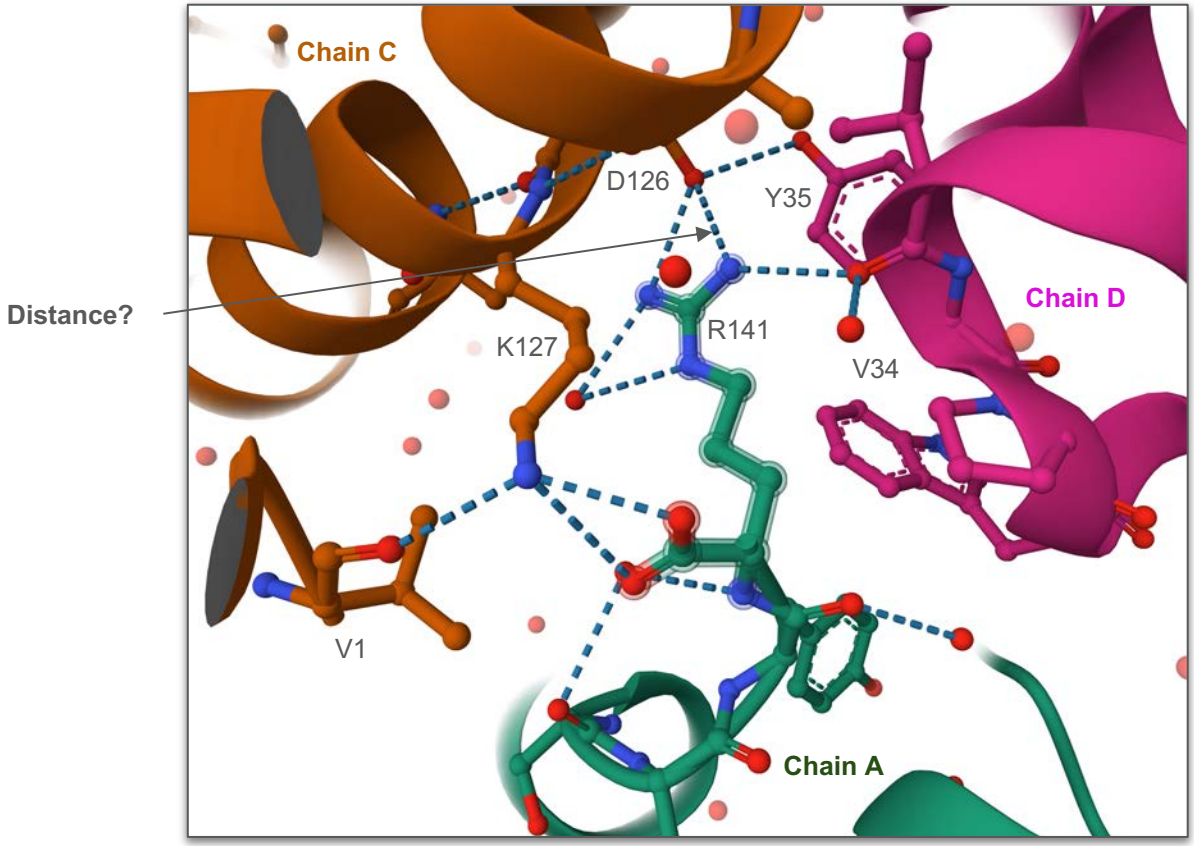
Deoxy-Hemoglobin (PDB ID 2dn2)



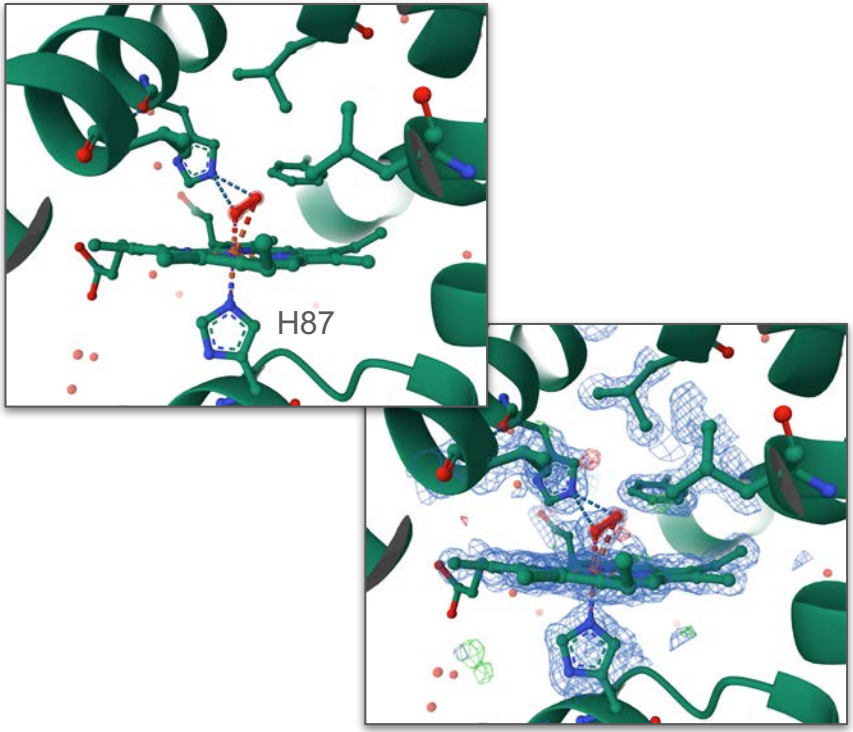
Oxy-Hemoglobin (PDB ID 2dn1)



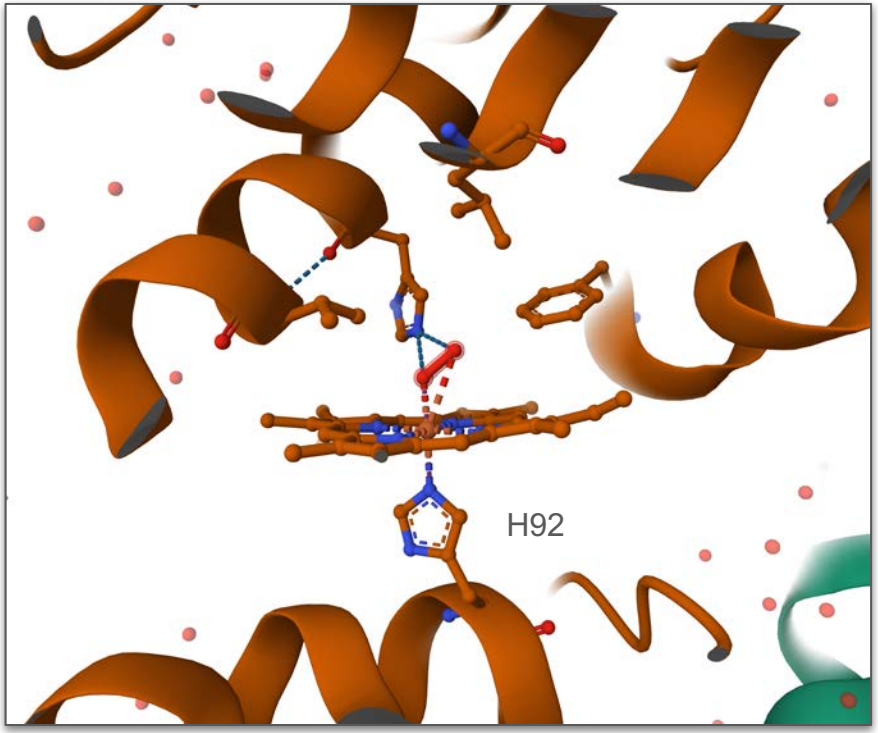
# Deoxy-Hemoglobin Interactions around an amino acid



# Hemoglobin - Examine Oxygen Binding



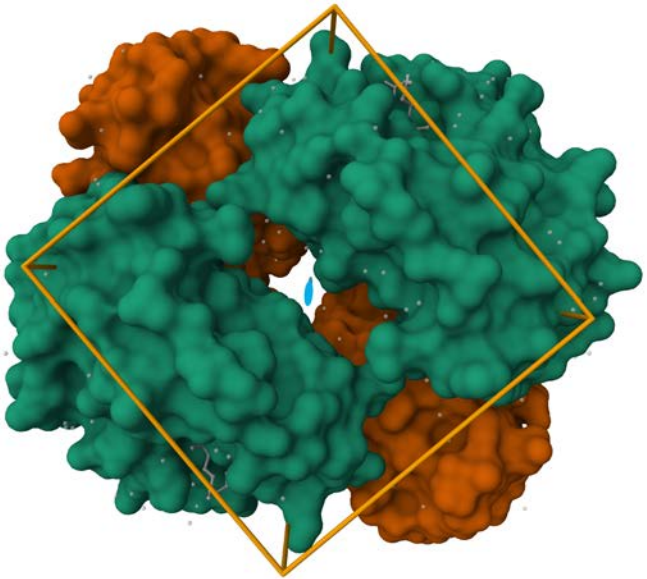

PDB ID 2dn1



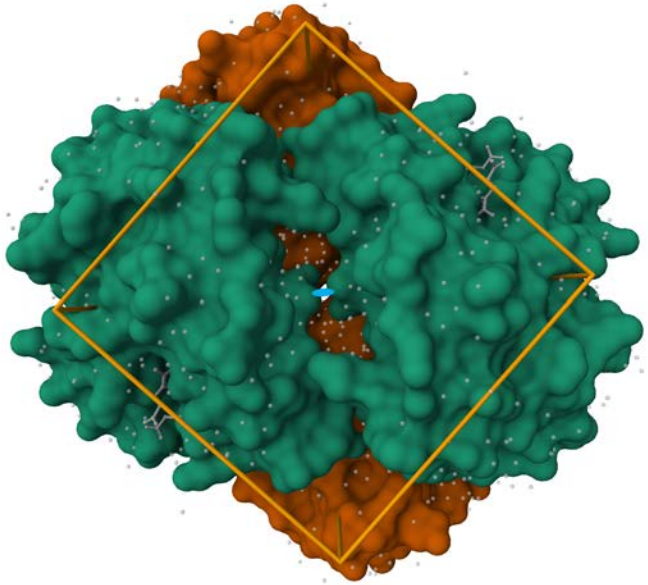
# Sickle Cell Hemoglobin

# Sickle Cell Hemoglobin - Conformational Changes

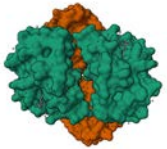
Deoxy-Hemoglobin S (PDB ID 2hbs)



Carbonmonoxy-Hemoglobin S (PDB ID 5e6e)

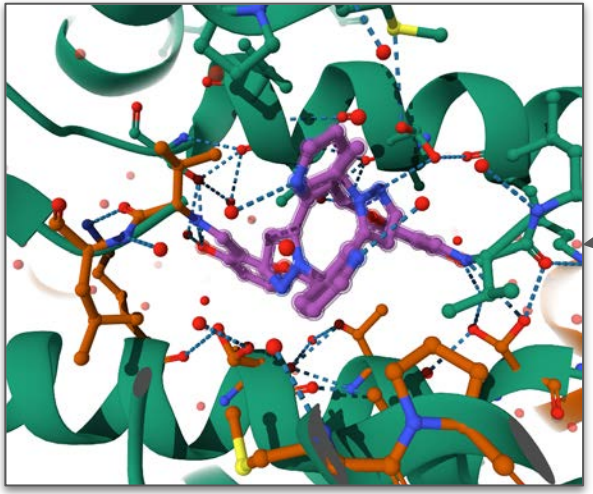


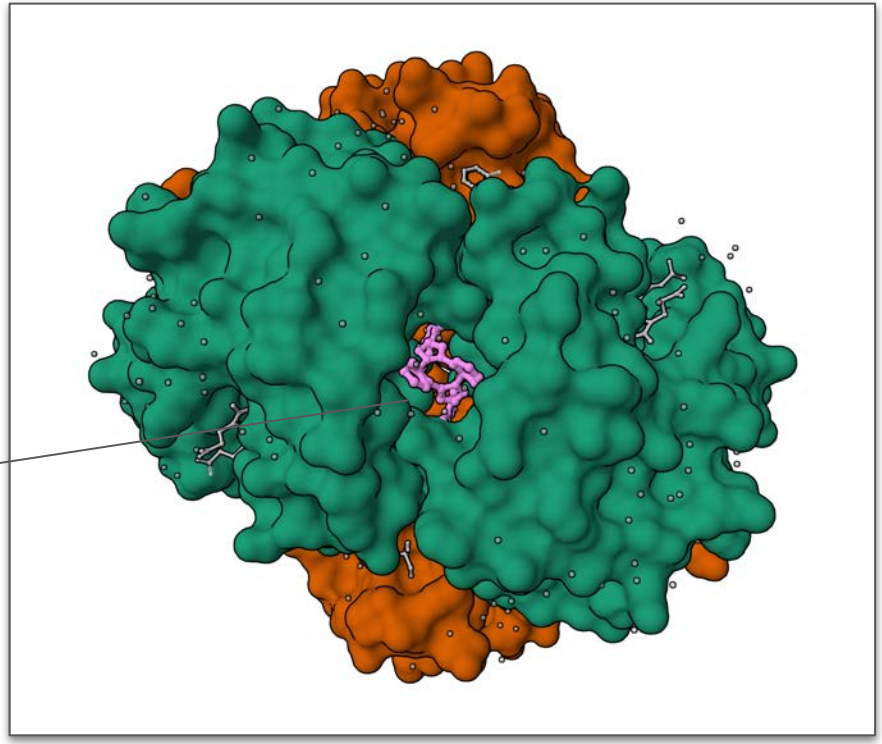
# Voxelotor bound to Carbonmonoxy HbS



PDB ID 2dn1

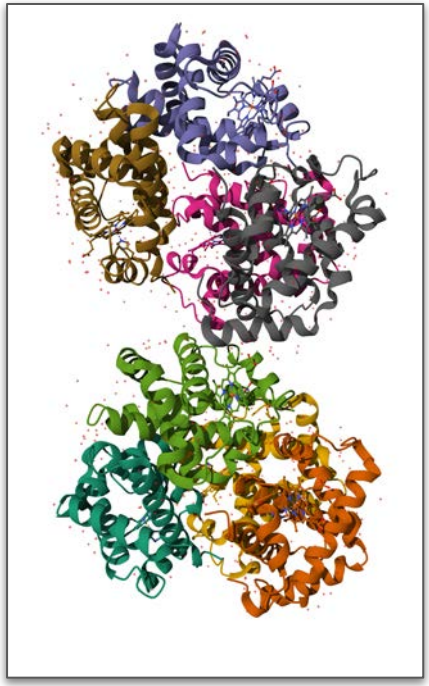
- Targets HbS polymerization
- Binds to the alpha subunit of HbS and stabilizing the oxygenated haemoglobin state

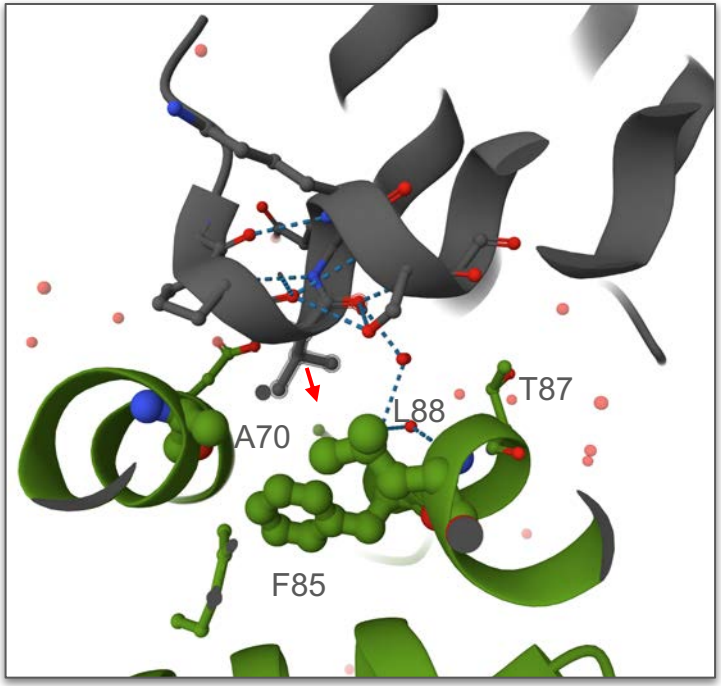


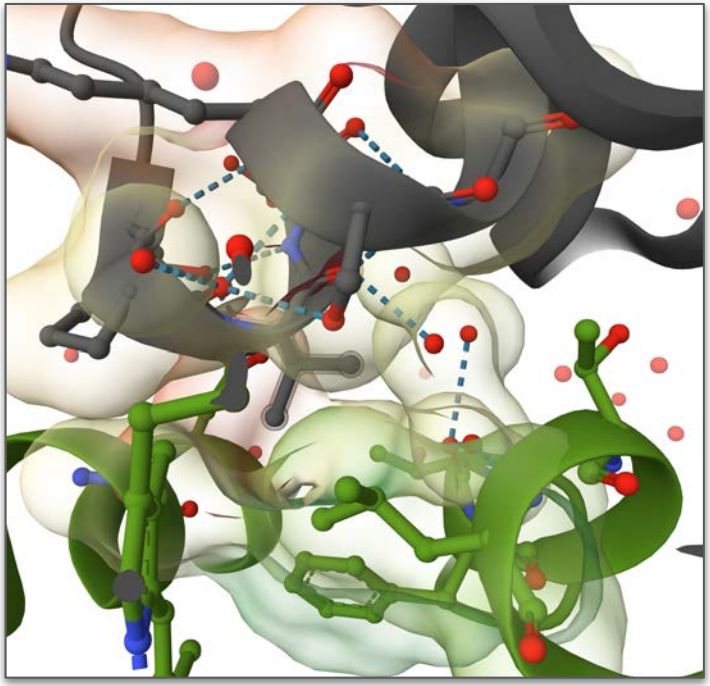


PDB ID 5e83

# Molecular Basis of Sickle Cell Disease





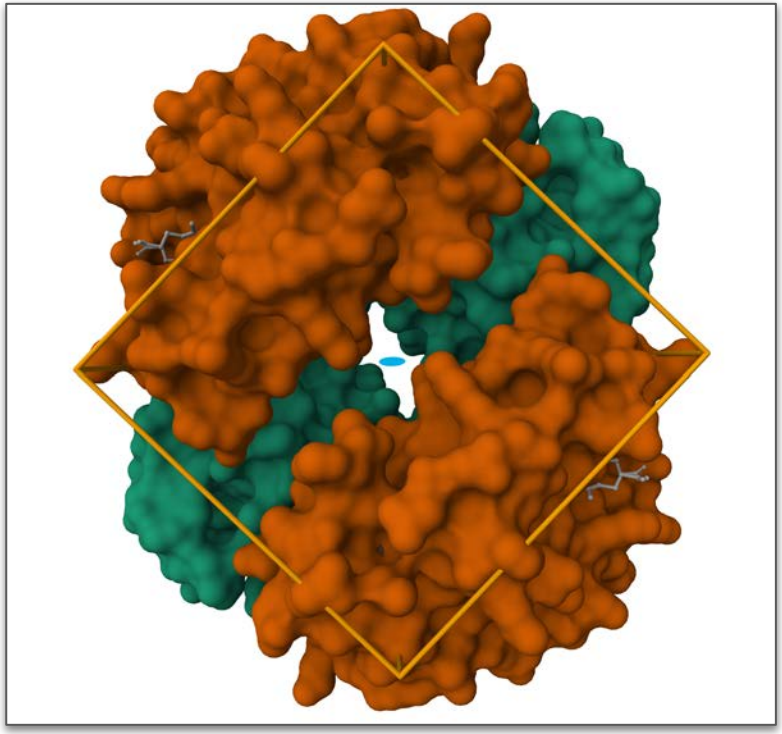



PDB ID 2hbs

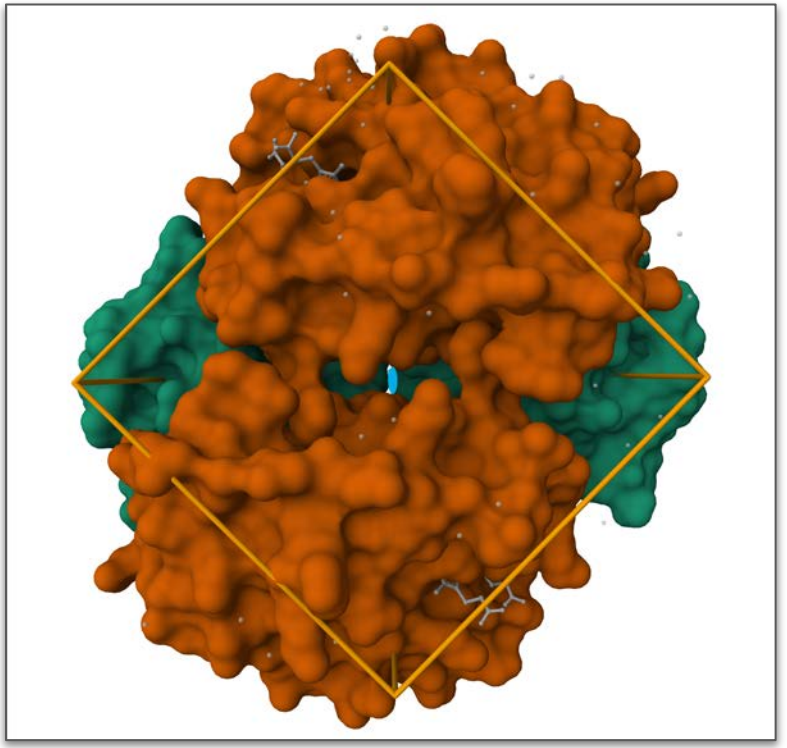
# Fetal Hemoglobin HbF

# Fetal Hemoglobin (HbF) Conformational Changes

Deoxy- HbF (PDB ID 1fdh)

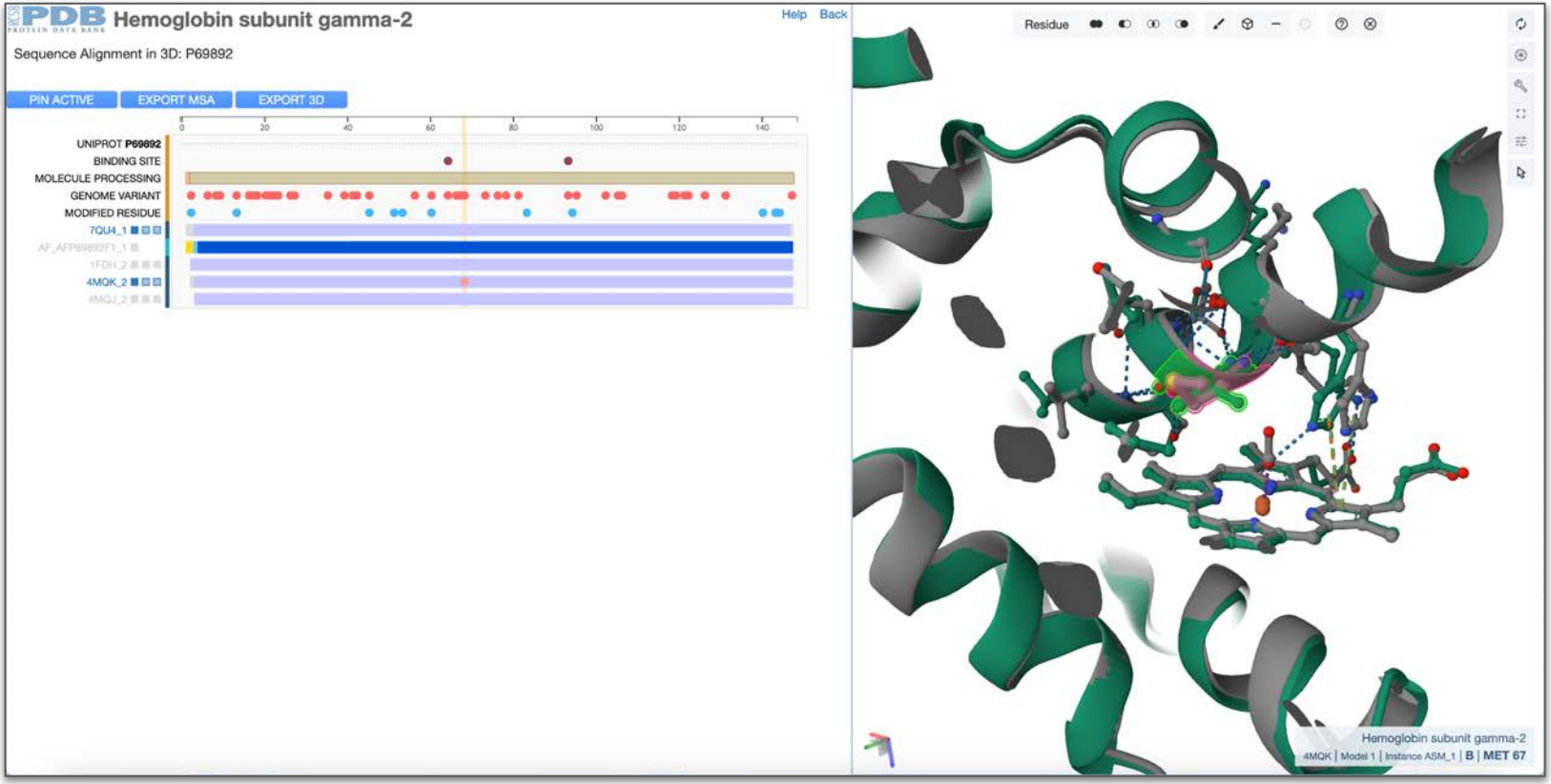


Carbonmonoxy- HbF (PDB ID 4mqj)



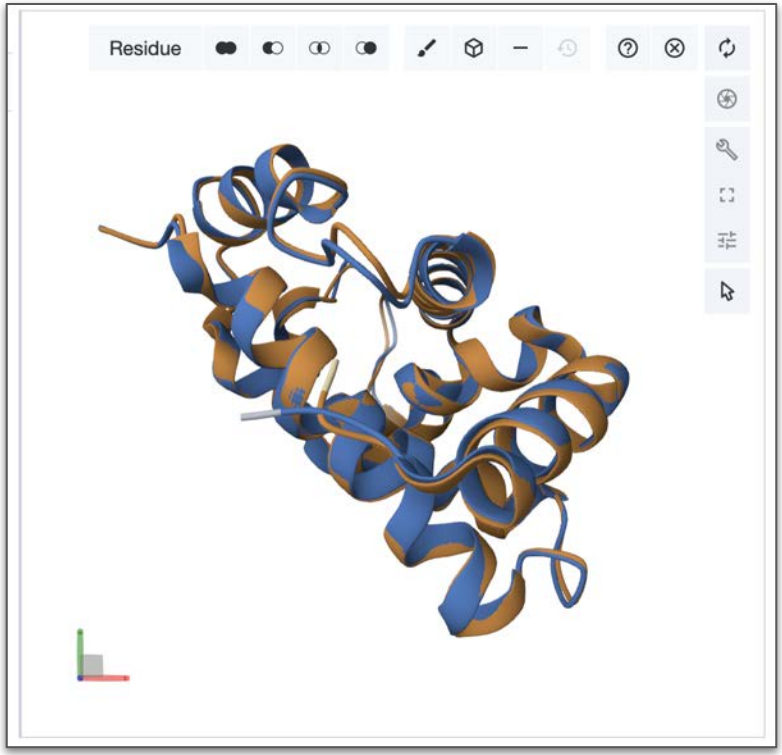
Are there HbF Mutations?
Can they cause disease?

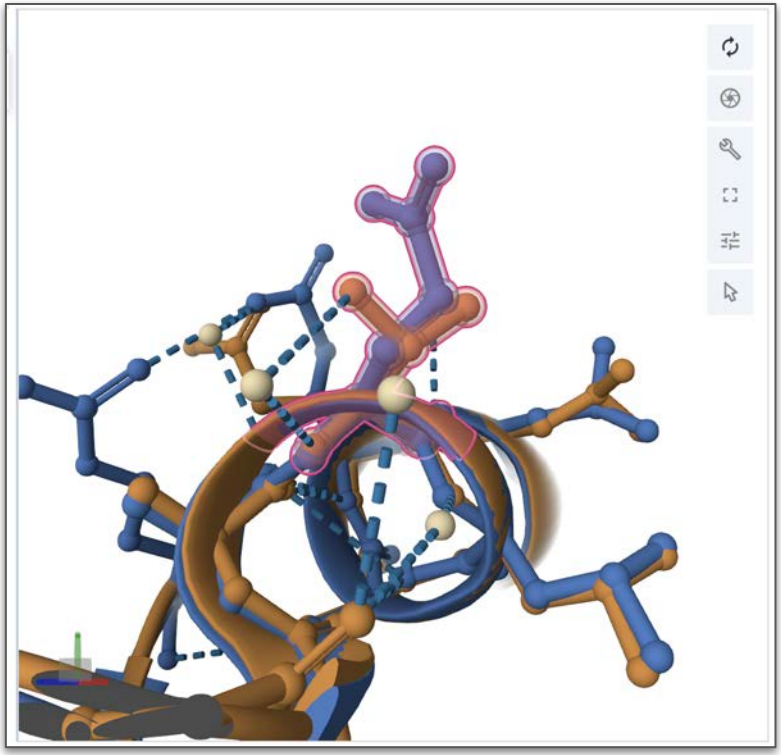
# Exploring Groups: Sequences and Structures



How similar are are the structures of Hb and HbF?

# Comparing Hemoglobin beta (2hbs) and gamma (1fdh)



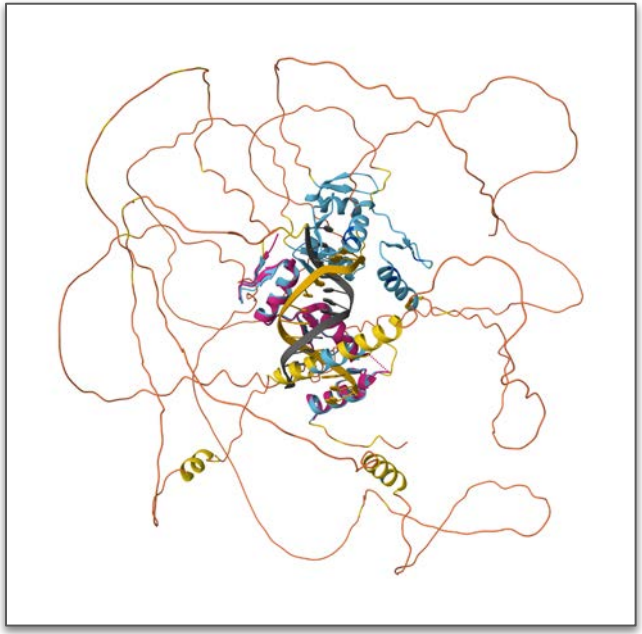
# BCL11A and Hemoglobin Synthesis

# BCL11A

BCL11A bound to gamma-globin HPFH region

PDB ID 6ki6

Comparing with the BCL11A (CSM, Alpha Fold)



Superpose AF_AFQ9H165F1 and PDB ID 6KI6

# Molecular Mechanisms of US FDA approved SCD Gene Therapies

FDA NEWS RELEASE

**FDA Approves First Gene Therapies to Treat Patients with Sickle Cell Disease**

Share | X Post | LinkedIn | Email | Print

**For Immediate Release:** December 08, 2023

Today, the U.S. Food and Drug Administration approved two milestone treatments, Casgevy and Lyfgenia, representing the first cell-based gene therapies for the treatment of sickle cell disease (SCD) in patients 12 years and older. Additionally, one of these therapies, Casgevy, is the first FDA-approved treatment to utilize a type of novel genome editing technology, signaling an innovative advancement in the field of gene therapy.

https://www.fda.gov/news-events/press-announcements/fda-approves-first-gene-therapies-treat-patients-sickle-cell-disease

# Lyfgenia

- Modify βA-globin gene (threonine [T] replaced with glutamine [Q] at position 87, T87Q or βA-T87Q-globin)
- Introduce into patients' hematopoietic stem cells (HSCs) with BB305 LVV.
- Transduced CD34+ HSCs put back in the bone marrow → produce red blood cells containing biologically active βA-T87Q-globin to produce functional Hb.
- βA-T87Q-globin sterically inhibit polymerization of HbS, limiting RBC sickling.

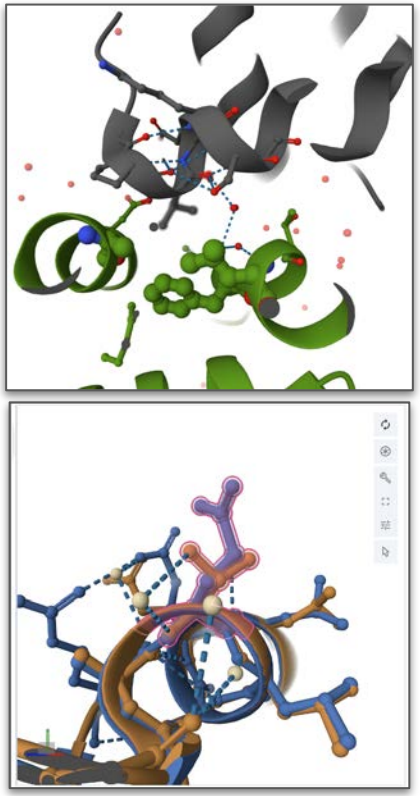
https://www.fda.gov/media/174615/download


https://www.lyfgenia.com/

# Efficacy of Lyfgenia

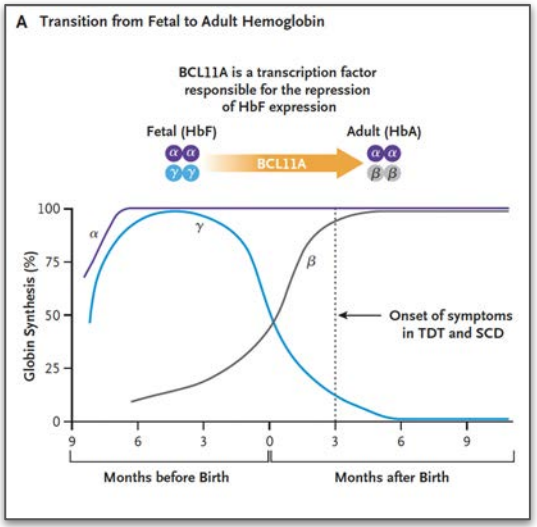
- Globin response (GR) was defined as meeting the following criteria for a continuous period of at least 6 months after drug product infusion:
  - weighted average hemoglobin AT87Q percentage of non-transfused total Hb ≥ 30% AND
  - weighted average non-transfused total Hb (HbS+HbF+HbA2+HbAT87Q) increase of ≥ 3 g/dL compared to baseline total Hb OR weighted average non-transfused total Hb ≥ 10 g/dL.
- 86% of 36 individuals treated achieved GR

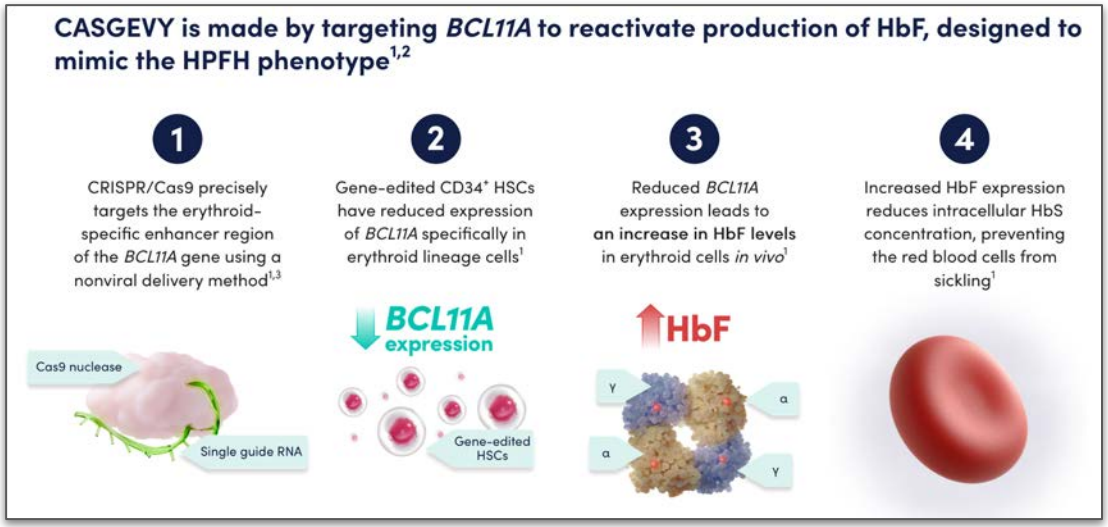
Package Insert - LYFGENIA (https://www.fda.gov/media/174610/download)



# Casgevy

- CRISPR-Cas9 used for targeting B-cell lymphoma/leukemia 11A (BCL11A)
- Reactivate HbF production (designed to mimic the HPFH phenotype)

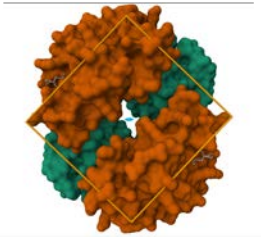



Frangoul et al., 2021; DOI: 10.1056/NEJMoa2031054

https://www.casgevyhcp.com/sickle-cell-disease/mechanism-of-action

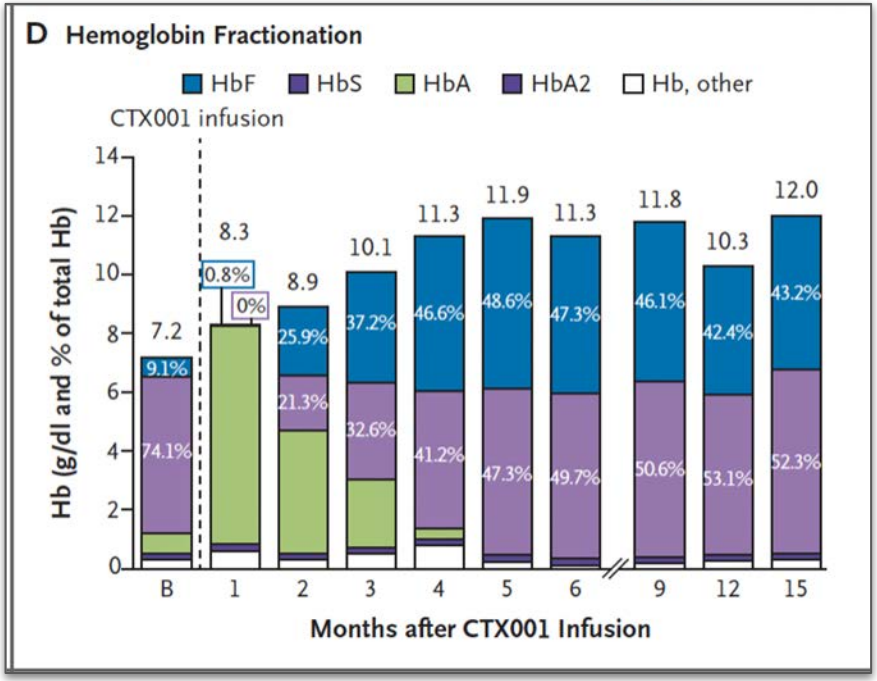
# Efficacy of Casgevy



PDB ID 1fdh

- The mean (SD) proportion of Hb comprised by HbF was 43.9% (8.6%) at Month 6 and was maintained thereafter
- Consistent with the increase in HbF levels, the mean (SD) proportion of circulating erythrocytes expressing HbF (F-cells) at Month 3 was 70.1% (13.8%) and continued to increase over time to 94.0% (12.4%) at month 6, with levels remaining stable thereafter, indicating sustained pan-cellular expression of HbF

Package Insert - CASGEVY
(https://www.fda.gov/media/174615/download)




Frangoul et al., 2021; DOI: 10.1056/NEJMoa2031054

# Summary of Mol* Functions

- What
  - structure(s) to visualize? - **Structure ID**s available or **Query** for structure(s)
  - is included in the structure being visualized? - **Structure Summary Page, Model vs Assembly**
- Where
  - is a specific feature, sequence, domain, ligand of interest? - Examine in **Mol***
  - do different structural and functional annotations map on the structure? - **Sequence Annotations in 3D**
- How
  - do structural features participate in interactions? - View **interactions in Mol***
  - to analyze and compare structures? - **Measure in Mol***, **Pairwise Structure Alignments**.
- When
  - do biomolecular structures perform their specific functions? - **Query** for specific contexts
  - are specific structures and functions conserved/similar? - **Groups**, **Sequence Alignments in 3D**
- Why
  - do specific structural features and interactions of a biomolecule enable its function? - *Integration, molecular stories, hypothesis development, design, save images/animations*

# RCSB Team

RCSB PDB PROTEIN DATA BANK RCSB.ORG info@rcsb.org


**Funding**

National Science Foundation (DBI-1832184)
National Institute of General Medical Sciences,
National Institute of Allergy and Infectious Disease,
National Cancer Institute (NIH R01GM133198)
US Department of Energy (DE-SC0019749)


**Management**

RUTGERS UC San Diego SDSC San Diego Supercomputer Center UCSF University of California San Francisco

WORLDWIDE PDB PROTEIN DATA BANK

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