**Waking Up Anna**

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**Part 3: Exploring GABA-A Receptor Structure and Function**

The pharmacology experiments showed that a substance in Anna’s CSF increased the activity of the GABA-A receptor with a mechanism similar to a benzodiazepine. The substance has not yet been identified so we cannot compare its chemistry or structure with known regulators of the GABA-A receptor yet. However, we can explore known structures of this receptor to learn more about the shape and structure of the GABA-A receptor itself. We can also learn more specifically where the various ligands bind and how they affect receptor function. This knowledge can help us to better understand Anna’s story in molecular detail.

*Box 4: Resource*

RCSB Protein Data Bank (**RCSB PDB**, [www.rcsb.org](http://www.rcsb.org)) provides access to 3D structural data of biological macromolecules (proteins, nucleic acids, carbohydrates and their various complexes). In addition, it provides information about the experiment used to derive the data, details about the molecules included in the experiment, and links to bioinformatics resources that can provide additional information about the protein/molecule of interest. Each structure in the PDB has a unique identifier called PDB ID. Atomic coordinates form the PDB can be explored and analyzed using various visualization software (e.g., Jmol, Pymol, UCSF Chimera, iCn3D).

* Search for the GABA-A receptor in the PDB ([www.rcsb.org](http://www.rcsb.org)) by typing in the protein name in the top search box. From the suggestions box that opens up as you type in the name, click on the GABA-A subunit alpha under the UniProt Molecule Name (since this subunit is present in most GABA-A receptor isoforms).

Q1. How many structures of the GABA-A receptor did you find in the archive? Why are there so many structures?

* Click on the **PDB ID 6i53** to open the structure summary page for this entry. This is the structure of GABA-A receptor. Review Box 5 and answer the following questions.

*Box 5: Navigating the Structure Summary Page*

1. **Title** - that tells you what the structure is about

2. **Snapshot** - of what the structure of the molecule/complex looks like.

3. **Authors** – who solved the structure

4. **Literature** –access the article that describes the structure. This section also includes links to PubMed page and the abstract of the article describing this structure, when available.

5. **Macromolecules** – All proteins and nucleic acids present in the structure are listed here. Each unique type of macromolecule or molecular chain is listed as a separate entity. There may be multiple copies of each molecule in the structure.

6. **Small molecules** – All ligands, ions, cofactors, inhibitors that are present in the structure are listed here. You can find links here to explore the interaction of this ligand with the target protein.

7. **Experimental details** – describe details about how the structure was determined

8. **Structure quality** – shows a slider that provides insights about the quality of the structure and its agreement with the experimental data and geometric standards.

See <http://pdb101.rcsb.org/learn/guide-to-understanding-pdb-data/introduction> for details

Q2. Explore the structure summary page to learn about the contents of the structure and fill in the table.

|  |  |
| --- | --- |
| PDB ID | 6i53 |
| Author(s) of entry |  |
| Year when the structure was published/ released |  |
| Structure determination method |  |
| # of entities |  |
| # of polymer chains |  |
| Names of proteins in these chains (chain ID) |  |
| # of different small molecule ligands in the structure and their identifiers |  |

Q3. Why do some of the protein subunits list multiple chain IDs on the structure summary page?

* Before you explore the structures of the GABA-A receptor any further, review Box 6.

*Box 6: Vocab*

**Residues**: Building blocks of biological macromolecules are sometimes referred to as residues. Depending on the context, this may refer to amino acids (frequent use) or a nucleotide (less common use).

**Chains**: The term chain is used to refer to covalently linked amino acids (polypeptide). Some proteins structures contain more than one polypeptide - each subunit of this structure is referred to as a chain. To help locate amino acids in the structure, each chain is given an identifier (called Chain ID) and each amino acid in the chain is assigned a number.

**Domains** are conserved parts of a protein that can evolve, function, has a stable three-dimensional structure and often can stably fold and exist independently (of the full protein). On the other hand, loops and linker regions between domains are often flexible and cannot be clearly seen in experimental structures. Their atomic coordinates may be missing from the file because the large protein was cut into smaller pieces and only the relevant structures are included in the experiment OR they were present in the experiment, but its location could not be seen due to high mobility.

**Complex assembly and stability**: Protein complexes can be assembled in vitro (outside the cell) to study the structure. In order to stabilize the assembly additional ligands or even polymer chains may be included in the experiment – for example

a. lipid-like or detergent molecules are included in membrane protein complexes to prevent them from aggregating or precipitating from the aqueous solutions

b. antibodies or other stable proteins/domains may be included in the experiment to facilitate assembly formation, enhance solubility of the complex, or trap the molecule/complex in a specific conformation.

* Click on the 3D structure tab on the Structure summary page and view the molecular structure of the GABA-A receptor.
* Interactively rotate and reorient the structure to get acquainted with it.
* Spend a few minutes playing around with the different pull-down menus to see some of the different ways this protein view can be adjusted.
* Color the structure displayed by secondary structure (i.e., color the alpha helices in one color and the beta strands in another color).

Q4. Can you identify the extracellular ligand binding domains and transmembrane domains in the GABA-A receptor structure? Which type of secondary structural elements (helices or sheets) make up these domains?

Q5: Make an image with the extracellular domain on top. Label the extracellular domain, the transmembrane domain and the megabody. Include the image below.

* In order to visualize and analyze the GABA-A receptor complexes in greater detail we will use an online molecular structure visualization tool, called iCn3D.

*Box 7: Resource*

**iCn3D** is a web-based visualization tool that allows users to directly open any structure from the Protein Data Bank (PDB) and visualize the structure. Users can interactively rotate the molecule/complex, select specific regions and represent them in different ways, compare structures, analyze interactions and make simple distance measurements.

* Go to iCn3D (<https://www.ncbi.nlm.nih.gov/Structure/icn3d/full.html>)
* Click on the button called File >> Retrieve by ID >> PDB ID so that a new window opens. Input the PDB ID of the structure you wish to visualize (e.g., 6i53) and click on Load.
* The structure opens in a new tab – rotate the molecule and examine the overall structure.
* Spend a few minutes playing around with the different pull-down menus to see some of the different ways this protein view can be adjusted.

Q6. How many polymer chains do you see? Take and screenshot of the structure and include it below.

* Display the secondary structure distribution in this structure by clicking on the Color button, then Secondary, and Sheet in Yellow options. This will color the all beta strands in yellow and the helices in red. Rotate the structure to examine the structure.
* Save an image of the structure colored by secondary structural features by clicking on the File button >> Save Files >> iCn3D PNG image.

Q7. Describe the distribution of the secondary structural features in this image.

Q8. In the above the red and blue discs around the structure represent membrane boundaries. Label “out”, “transmembrane”, and “in” to indicate which parts of the structure are outside, in the membrane, and inside the cell. Explain how you figured this out. (*Hint: Read the abstract of the article describing the structure deposited as PDB ID 6i53 an examine the structure summary page carefully for clues.*)

* Examine the structure of a single protein in the pentameric GABA-A receptor by selecting one of the GABA-A receptor chains – the one with chain ID A.
* Click on the button Select >> Defined Sets >> a new window opens titled Select sets. In this window click on 6I53\_A to select it and notice that part of the structure in the graphics window lights up with a yellow halo. This is chain A.

Q9. What is the name of the protein in chain A? (Hint: Refer back to the structure summary page for this PDB entry to find out the name of the protein. Alternatively, you can also consult your table in Part 3, Answer 2.)

* In order to hide the other chains, and only see the protein with chain ID A:
  + click on Select >> Inverse - this should highlight all proteins and ligands in the structure (except chain A).
  + click on Style >> Proteins >> Hide to hide all currently selected protein chains
  + click on Style >> Chemicals >> Hide to hide all ligands shown in stick representation.
  + click on Style >> Side Chains >> Hide to hide any side chains that were shown in the selected chains.
  + click on View >> Disulfide Bonds >> Hide to hide all disulfide bonds shown.

What remains in the graphics window is the protein chain A (and a few amino acid side chains).

* + Select chain A (as described above) and color >> spectrum. This colors that chain A from N- to C-terminus according to the rainbow color scheme (N-terminus is colored Violet/blue to C-terminus, shown in red).

Q10. What is the main secondary structural element in the N-terminal domain? Is this outside or inside the cell? What is the main secondary structural element in the C-terminal domain? Is this outside or inside the cell? Include an image to support your answer.

* + The GABA-A receptor proteins belong to the Cys-loop receptors. Each chain in this receptor has a disulfide (S-S) bond and the stretch of amino acids between the linked Cys form the Cys-loop.
* Identify the Cys forming these S-S bonds in each of the 5 chains.
  + Click on View >> Disulfide bonds >> Export pairs. Open the results in a browser window.

Q11. Which residues form the S-S bond in chain A?

* Click on the 6I53\_A option in the Select sets window so only the sequence of the Chain A is shown.
* Find the C (for Cys) in the sequence window representing Cys 136 and 153. In this window, click and drag on all the residues between these residues. This selects these residues in the graphics window too.
* Color the selected residues by clicking on Color >> Unicolor >> magenta (or any other color of your choice that stands out). Save an image or take a screenshot of this structure.

Q12. Where in the structure is the Cys-loop located? Show the figure you saved above and explain why this region may be important in the function of the protein.

Now that we have some understanding of the structure of each of the GABA-A receptor proteins let us examine the gate through which the chloride ions enter the cell.

* Reload the iCn3D page for the PDB entry 6i53 to see the full structure again.
* You can toggle off the membrane representation by clicking on View >> Toggle Membrane.
* Select Chain A (see instructions above) and color it by the Spectrum option (N-terminus violet/Blue to C-terminus red).
* Orient the structure so that you are looking into the central channel from the inside of the cell.

Q13. Which of the 4 helices in chain A lines the chloride ion channel?

Click on any residue on this helix to select an atom and expand the selection by pressing on the up arrow.

Q14. What is the amino acid sequence of this helix? (Hint: Read off the sequence from the sequence window.)

We will use the P (Pro) in this helix as a marker for measuring distances in different GABA-A receptor complexes. Make sure you not the residue number and sequence around this Pro so that you can identify it in other structures.

* Select this Pro in chain A and D (since both these are GABA-A alpha chains) by clicking and dragging on it with the shift button pressed.
* Display the side chains by clicking on Style >> Side Chains >> Ball and Stick
* Now click on View >> Zoom in selection.
* Measure the distance between these side chains by clicking on View >> Distance >> Measure.
* Click on the 2 atoms between which you wish to measure the distance and click on Display in the box that opened.
* This should display the distance on the screen. In case you cannot see the distance read off the distance from the text command line/logs window just below the graphics window.

Q15. What is the distance between the 2 Pro atoms in the GABA-A alpha chains?

Explore the structure of GABA-A receptor in complex with GABA (PDB ID 6dw0).

* Open the file in iCn3D and explore the structure as above.
* Open the Sequences and Annotations window and scroll to the bottom. Select the 3 ABU ligands – these are the GABA molecules.
* Display these prominently by clicking on Style >> Chemicals >> Sphere.

Q16. Where in the structure are the GABA molecules bound? Outside or inside the cell? Which GABA-A receptor chains are they bound to? Support your answer with a figure.

Explore the binding environment of one of the GABA molecules as follows.

* In the sequence window select on the first GABA (ABU) by clicking and dragging on it.
* Now click on View >> H-bonds & Interactions >> Display (with default options)]. by Distance >> use the default options with H-bonds, salt bridges, contacts/interactions checked in the new window that opens and click on Display
* Click on Style >> Side chains >> Sticks; then View >> Zoom in selections; and then Color >> Atom

Q17. List the names of any 2 amino acids that forms hydrogen bonds with the GABA (ABU). Support your answer with a suitable figure.

* Examine the interactions of these amino acids with the GABA molecule. Use the following concept box to guide your explorations.

*Box 8: Concepts*

Biomolecular structural stability, interactions and functions are dependent on various non-covalent interactions. Some key interactions in molecular structures are:

**Hydrogen bonds** - formed between two partially negatively charged atoms with a hydrogen atom between and covalently linked to one of them. e.g. in structures look for examples of O/N … H\_\_O/N, where … denotes hydrogen bond and \_\_ denotes a covalent bond

**Salt bridges** or **ionic interactions** - formed between oppositely charged amino acid side chains and/or charged ligands/ions. e.g. in structures look for interactions between Lys/Arg/His and Glu/Asp. These interactions may also involve phosphate groups and ions such as K+, Na+, Cl- etc.

**Hydrophobic interactions** - formed between hydrophobic amino acid side chains positioned away from the aqueous environment. e.g. look for regions with large numbers of carbon and hydrogen atoms in close proximity. Aliphatic amino acids such as Ala, Leu, Val, Ile participate in hydrophobic interactions.

**Pi stacking** - seen between amino acids with aromatic side chains (e.g. Tyr, Trp, Phe). Pi clouds of aromatic rings interact with each other in staggered stacks, face to edge interactions, or interactions with positively charged amino acid side chains (pi-action interaction).

Q18. List 2 other non-covalent interactions that hold the GABA molecule in its position. Support your answer with a suitable figure.

Q19. What is the distance between the Pro residues in the second transmembrane helix of the GABA-A receptor alpha chains? Compared to the distance in the GABA-A apo structure, what can you say about the chloride channel in the GABA bound receptor – is it open or closed? Provide your evidence(s) and any observations along with images to support it.

Open another structure – GABA-A receptor in complex with GABA and Valium (PDB ID 6hup). Valium is an example of a benzodiazepine.

* Open the file in iCn3D and explore the structure as above.
* Open the Sequences and Annotations window and scroll to the bottom.
  + Select the GABA molecules (ABU); display these prominently by clicking on Style >> Chemicals >> Sphere; Color >> Atom
  + Select the Valium molecules (DZP); display these prominently by clicking on Style >> Chemicals >> Sphere; Color >> Unicolor >> red.

Q20. Where in the structure are the GABA and Valium molecules bound? Which GABA-A receptor chains are they bound to? Support your answer with a figure.

Q21. What is the distance between the Pro residues in the second transmembrane helix of the GABA-A receptor alpha chains? Compared to the distance in the GABA-A apo structure, what can you say about the chloride channel in the GABA bound receptor – is it open or closed? Provide your evidence(s) and any observations along with images to support it.

**Part 4: Waking up Anna**

While the substance in Anna’s CSF was mimicking a benzodiazepine by acting as an allosteric modulator of the GABA-A receptor, injecting Anna with Flumazenil had the opposite effect and woke her up. Explore the structure of the GABA-A receptor in complex with GABA and Flumazenil to understand where it binds and how it regulates the receptor function.

* Open the file PDB ID 6d6t in iCn3D and explore the structure as above.
* Open the Sequences and Annotations window and scroll to the bottom.
  + Select the GABA molecules (ABU); display these prominently by clicking on Style >> Chemicals >> Sphere; Color >> Atom
  + Select the Flumazenil molecules (FYP); display these prominently by clicking on Style >> Chemicals >> Sphere; Color >> Unicolor >> a color of your choice so that it stands out.

Q1. Where in the structure are the GABA and Flumazenil molecules bound? Which GABA-A receptor chains are they bound to? Support your answer with a publishable figure drawn using iCn3D.

Q2. Another structure of the same complex was reported as a different conformer. Open the structure PDB ID 6d6u in a different window. Can you see any major differences in the structures of the complex in PDB IDs 6d6t and 6d6u? List one difference and support your answer with an illustration.

Ans: The 2 models look similar but the transmembrane helices in both structures are twisted around the chloride channel axis to different degrees, especially near the Flumazenil binding site – see figures below

Q3. With a hand drawn model summarize the structure of the GABA-A receptor (as seen from the outside of the cell). You may use the pentameric structure shown below to draw and mark in the model where GABA, Valium, and Flumazenil bind. Remember to label the alpha, beta, and gamma chains of the GABA-A receptor.

Ans:



Q4. Based on your explorations of these structures, can you explain the mechanism of Flumazenil’s action in waking up Anna.

Q5. How would you design the next experiment to figure out if the mechanism that you are proposing can explain Anna’s recovery from hypersomnia (with Flumazenil treatment)? Briefly describe in 3-4 sentences what experiments you would do and why?