**Waking Up Anna**

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**Preparation:**

Prior to the case discussion in class (as a homework assignment), get acquainted to the case.

* Watch a video (<https://www.youtube.com/watch?v=V9gnvWtta4M>) to hear Anna’s personal account and how doctors at the Emory Sleep Center in Atlanta, GA found a treatment that finally helped her feel awake.
* Read the Emory news article, “An antidote for hypersomnia”, by Baker and Eastman, published on Nov. 21, 2012 describing this treatment (<http://news.emory.edu/stories/2012/11/antidote_for_hypersomnia/>).
* Read the abstract of the peer reviewed scientific article describing this work at <https://stm.sciencemag.org/content/scitransmed/4/161/161ra151.full.pdf>

**Part 1: Can’t Get Enough Sleep**

We have all been sleep deprived at some point in time and can relate to how difficult it becomes to focus or carry out simple routine tasks. For Anna Sumner, it was different – she craved sleep. This case will focus on understanding the molecular basis for signaling in the Nervous System and the cause and treatment of Anna’s sleep crises.

Based on the video you watched and articles you have read about this case answer the following questions.

Q1. Describe in 1-2 sentences the main difference between the popular news report and the peer-reviewed scientific article.

Q2. For the three sources of information that you viewed/read for this case list one benefit and one drawback in the table below.

|  |  |  |
| --- | --- | --- |
| Source | Benefit | Drawback |
| Video |  |  |
| News report |  |  |
| Journal article |  |  |

Q3. Define the prefixes Hypo- and Hyper- used in the description of this case in the peer-reviewed manuscript. Find at least one example where this meaning is used

Cellular communication in the brain occurs when neurotransmitters released from one cell activate receptors on the surface of another cell. This chemical signal changes the physiology of the second cell to elicit a response, as shown in figure 1.

A close up of a logo

Description automatically generated

Figure 1: Neuronal synapse showing a. presynaptic cell, b. post synaptic cell, c. neurotransmitters, d. synaptic vesicles, e. receptors

Q4. Can you redraw the above neuronal synapse shown above and label the diagram with the 5 labels a. presynaptic cell – e. receptors, listed in the figure legend.

A close up of a logo

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*Box 1: Vocab*

**Neurotransmitters** are small molecules derived from basic building blocks of life, e.g., amino acids. For example, gamma amino butyric acid (or GABA) is derived from the amino acid Glutamate by a decarboxylation reaction. They bind to proteins (such as receptors) and affect their functions. They are also referred to as ligands and may include naturally occurring molecules or man-made drugs.

**Receptors** are large transmembrane proteins that change shape when they bind to small molecules. Many clinically important drugs also bind to receptors in the brain to change our behavior, to treat diseases, and in special situations like inducing anesthesia for surgery.

There are many different combinations of neurotransmitters and receptors in the nervous system that add together to control the types of physiological and behavioral responses that we can see in ourselves. Two main types of neurotransmitter receptors are listed here:

1. **Metabotropic** receptors control metabolic pathways inside the cell, which can change the activity and expression of proteins.
2. **Ionotropic** receptors open pores, or channels, to allow specific ions to cross the cell membrane. These “ion channels” alter the electrical properties of the membrane to increase or decrease the likelihood that the cell will continue the chain of communication by firing an action potential.

Some neurotransmitters (e.g. glutamate) are excitatory (i.e., make it easier to fire action potentials while others (e.g., GABA) are inhibitory (i.e., make it harder to fire action potentials).

Q5. Review Figure 1 again and examine the rectangles closely - do you see anything special about the receptors and their interaction with the neurotransmitters?

* Here we will focus on the γ-aminobutyric acid (GABA) neurotransmitter system. There are two main types of GABA receptors. GABA type A (GABA-A) receptors are ionotropic and GABA type B (GABA-B) receptors are metabotropic, but the overall response of both types of receptors is to inhibit the activity of the cell.
* GABA-A receptors are pentameric, composed of 5 transmembrane protein subunits that together form a chloride ion-selective channel. This channel is open when the neurotransmitter GABA binds to the receptor. The GABA-A receptor also responds to a wide variety of drugs, *e.g.* benzodiazepines (a sedative), anesthetics and depressants. A simple cartoon of the GABA-A receptor is shown in Figure 2 along with the binding sites of various ligands.

A close up of text on a white background

Description automatically generated

Figure 2: GABA-A receptor, chloride (Cl−) ionophore complex. The cut-away view demonstrates binding sites for a variety of compounds that influence the function of the receptor complex. (Adapted from Olsen, R.W. and DeLorey, T.M., (1996), GABA Receptor Physiology and Pharmacology, Basic Neurochemistry: Molecular, Cellular and Medical Aspects. 6th edition.)

Let’s review the GABA neurotransmitter system.

Q6. What is the main role of GABA in the nervous system?

Q7. The GABA-A receptor is a transmembrane protein. Where would you expect a chemical signal (GABA, Benzodiazepine etc.) to bind this receptor? Circle ONE and explain your choice.

1. extracellular side
2. transmembrane domain
3. intracellular side
4. in the central channel

* Binding of neurotransmitters triggers ion channels to open. When GABA binds to the GABA-A receptor, the ion channel is open and chloride ions can cross the cell membrane. Other ligands, including clinically important drugs, can also bind to the GABA-A receptor to alter its function by opening or closing the Cl− channel.

*Box 2: Vocab*

**Agonists**: These are drugs or molecules that turn on the function of a protein. The natural ligand usually acts as an agonist.

**Antagonists**: These are drugs or molecules that decrease or inhibit the function of a protein.

**Allosteric modulators**: The word root “allo” means “other”. These are drugs or molecules that bind at a location other than the natural ligand’s binding site. Modulators could be positive (increase activity of the protein) or negative (decrease its activity).

Q8. Predict the effect of an **AGONIST** binding to the GABA-A receptor. Will the Cl− channel open, close, or remain unaffected by this drug? Can you list some examples of GABA-A receptor agonists?

Q9. Predict the effect of a **POSITIVE ALLOSTERIC MODULATOR** binding to the GABA-A receptor. Will the Cl− channel open, close, or remain unaffected by this drug? Can you list some examples of GABA-A receptor positive allosteric modulators?

Q10. Predict the effect of an **ANTAGONIST** binding to the GABA-A receptor if it occupies the same site that GABA would normally bind. Will the Cl− channel open, close, or remain unaffected by this drug?

Q11. **Challenge question**: What would happen if you increase the concentration of GABA and keep the concentration of the antagonist the same?

**Part 2: A Clue in the Spinal Fluid**

After excluding known causes of sleepiness doctors collected a sample of Anna’s cerebrospinal fluid (CSF) to look for clues about the unique pharmacology within her sleepy brain. Researcher scientists analyzed her sample along with 31 other hypersomnolent patients and found that it contained a substance that increased GABA-A receptor function in cultured cells!

Let’s explore the evidence that scientists gathered and discover how this observation can help understand Anna’s case.

*Box 3: Experimental techniques*

**GABA-A receptor.** GABA-A receptors are pentameric. Although there are many different isoforms of the protein, the most common type of GABA-A receptors found in the human brain are composed of 2 alpha (**α**), 2 beta (**β**), and 1 gamma (**γ**) subunit.

**Cultured cells express the receptor:** These GABA-A receptor protein subunits can be recombinantly expressed in a cultured cell line (e.g. HEK293 cells) that form functional receptors for laboratory study.

**Patch clamp** is an experimental technique used to measure the changes in the electrical properties of cell membranes. Important ions, like Na+, K+, Ca2+, and Cl−, are present in different concentrations inside and outside neuronal cells leading to a **membrane potential** difference in charge. When channels are open, ions can move across cellular membranes leading to rapid and transient changes in the distribution of these charged particles. The movement of ions is recorded as **current**. These electrical signals are transmitted through neurons to trigger physiological changes. These cells can be examined by a technique called “patch clamping” to determine whether or not the channels in these receptors are open or closes in the presence of different ligands.

In these experiments, when the GABA-A receptor channels are closed there is a baseline reading. GABA and/or other GABA-A receptor agonists open the chloride channels to let negative ions (Cl−) into the cells. The patch clamp records this entry of Cl− ions as a downward deflection from the baseline. The larger the deflection (or dip) in the recording the more the Cl− ions have entered, inhibiting the neuron.

Scientists used patch clamp electrical recordings on HEK293 cells expressing the human α1, β2, and γ2 subunits of the GABAA receptor to test CSF effects on inhibitory chloride currents. First, they measured currents triggered by 10 μM GABA alone (control, trace a) to establish a baseline. Next, hypersomnolent patient CSF was applied alone and they observed a negligible chloride current (trace b). This response was equal to what would be expected from normal GABA concentrations in typical CSF. Next, hypersomnolent patient CSF was applied together with 10 μM GABA (trace c). Researchers were astonished to find that the current was doubled. They would only expect to see that kind of increase in the presence of a positive allosteric modulator like a benzodiazepine! Luckily, they had a pharmacological tool to determine if something was binding to the benzodiazepine site. Flumazenil is a competitive antagonist that blocks benzodiazepine binding. When flumazenil was applied together with 10 μM GABA and the hypersomnolent patient CSF sample (trace d) they saw that the effect was reversed! Finally, to make sure that everything was working correctly, they verified that flumazenil does not change GABA-A receptor activity with GABA alone (trace e) and that currents evoked by 10 μM GABA alone returned to baseline levels (trace f) after all other pharmacological agents were washed away. The data for these experiments is shown in Figure 3. Vertical calibration bars equal 200 pA (picoAmps) and horizontal calibration bars equal 5 s.

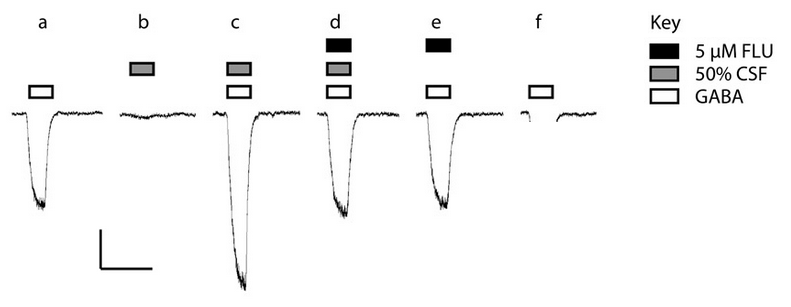


Figure 3. Chloride currents recorded from HEK293 cells expressing human GABA-A receptor.

Q1: Label the calibration bars with proper units and scale. Choose one word to describe what is being depicted in each direction.

Q2. Compare the chloride current traces shown in b. and c. and explain the conclusion that can be drawn from your observation.

Q3. Compare the chloride current traces shown in c. and d. and explain the conclusion that can be drawn from your observation.

Q4. Complete the figure. Draw the current trace that would be elicited by application of 10 μM GABA after washout of pharmacological agents that had been co-applied throughout the experiment in “trace f” as described above. What are traces e and f showing about the experimental design?

Q5. Based on the traces above, which of the following statements is correct?

1. Only in trace c. the GABA-A receptor is open and Cl− ions are flowing into the cell
2. The substance in Anna’s CSF can bind to GABA-A receptor and open the Cl− channel
3. The substance in Anna’s CSF needs GABA in order to open the Cl−channel
4. Flumazenil can close the GABA-A receptor Cl− channels
5. When the GABA-A receptor is open K+ ions are flowing out of the cell

**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?