**A Case of Severe Insulin Resistance**

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**Part 3: Insulin Resistance in Molecular Detail**

Megan wanted to “see” how a single mutation in Akt-2 could have such a big impact on insulin signaling. She also wanted to understand why changing the Arg at position 274 to His would have such a big effect on the activity of the enzyme. She decided to look at the structure of the protein in atomic detail, so went to the Protein Data Bank.

*Box 5: 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 various bioinformatics resources that can provide additional information about the protein/molecule of interest. Each structure in the PDB is identified by a unique identifier (called PDB ID). Atomic coordinates form the PDB can be visualized and analyzed using various visualization software (some available from RCSB PDB).

1. Search for Akt-2 protein structures in the PDB ([www.rcsb.org](http://www.rcsb.org)) to see what structure(s) is/are available. Type in the protein name Akt-2 in the top search box and click on the Protein Kinase Akt-2 under UniProt molecular name (in the suggestions box that opens up). Examine the list of PDB structures that match this query and answer the following:

Q1. List the PDB identifiers and titles for the 2 structures that contain Akt-2 protein – (one in its inactive form and one where it is activated).

Ans:

|  |  |
| --- | --- |
| PDB ID | Title |
|  |  |
|  |  |

When identifying the relevant PDB structures keep the following ideas in mind:

*Box 6: Concept*

Structures of **inactive enzymes** are often apoenzymes – i.e. without any substrate, cofactor etc. bound to it. In some instances, mutations in the active site residues will result in inactive enzyme – which does not function, even in the presence of relevant substrate(s) and cofactor(s).

Structures of **active enzymes** are seen either as structures trapped in a transition state complex, with a substrate/ cofactor analog and or inhibitor bound. Some active enzyme structures may also be product complexes.

Q2. Can you tell from the structure title what the active and inactive Akt-2 structures contain?

1. Open the structure summary pages to learn more about these two structures.

*Box 7: Resource*

***What can you find on 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. *Note you can look at the deposited coordinates (called asymmetric unit) and one or more biological assemblies by clicking on the arrows above the image box*

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

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

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

*Note their name, source, chain identifiers (IDs) and links to the protein sequence database (UniProt). Large proteins with multiple domains may be cut into smaller pieces – a short peptide or a single domain and included in the experiment.*

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 the structure determination

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

Q3. Explore the structure summary pages for both entries to complete the table below.

Ans:

|  |  |  |
| --- | --- | --- |
| Inactive Akt-2 PDB ID: | Authors of entry |  |
| Macromolecules |  |
| Small molecules |  |
| Activated Akt-2 PDB ID: | Authors of entry |  |
| Macromolecules |  |
| Small molecules |  |

Q4. Click on the 3D structure tab on the Structure summary page of the inactive Akt-2 structure and view it. Color the protein by secondary structural elements. What is the overall shape of the protein? Where are the different secondary structural elements (alpha helices and beta sheets) located in this structure? Take a screen shot of the structure and include it here.

1. In order to visualize and analyze the Akt-2 structures in greater detail we will use an online molecular structure visualization tool, called iCn3D.

*Box 8: 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., 1o6k) and click on Load.
* 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.
* Orient the molecule so that you can clearly see all components present in the structure. Save an image by clicking on File >> Save files >> iCn3D PNG image.

Q5. Where are the substrate and cofactor molecules in this structure? Import the image saved above to powerpoint or any other graphics software and label in the image appropriately.

*Box 9: A Mini Lesson on Akt-2*

**Akt-2** is a Serine/Threonine protein kinase that is itself activated by phosphorylation at Thr309 and Ser474. During the activation of this enzyme, the enzyme PI3K phosphorylates Thr309, while Ser474 is phosphorylated by mTORC2. Thus Akt-2 aggregates signals from multiple proteins and functions as a signaling node.

To study the activated form of Akt-2, Thr309 and Ser474 may be phosphorylated or mutated (to Glu and Asp, respectively) to mimic the phosphorylated amino acids charge and interaction.

To learn more read the review article Cell. 2007 Jun 29; 129(7): 1261–1274. doi: 10.1016/j.cell.2007.06.009

1. A linear schematic of the Akt-2 protein showing the domains, specific amino acid residues that are phosphorylated, and the one that was mutated in the proband is shown in Figure 1B (shown below for convenience).

A close up of text on a white background

Description automatically generated

Figure 1B from George et al., 2004.

Let us now locate this specific residue that was mutated in the proband (R274) in the 3D structure.

* Click on the button called Windows >> View Sequences & Annotations.
* Click on the Details button to see the one letter code sequence of all the protein chains in the structure.
  + Locate the R274 in the sequence, click and drag on the residues in the sequence and annotation window. The residues will be highlighted in yellow, both in the sequence and graphics windows.
  + Click on Style >> Side chain >> Stick. Now color this amino acid by clicking on Color >> Unicolor >> Cyan.

Q6. Where is this amino acid located in relation to the active site, substrate, and cofactors?

1. Explore the neighborhood of this residue to find out why changing it to His has a big impact on the enzyme activity.
   * While the R274 is selected (highlighted in yellow), click on Select >> by distance >> a new window opens. Click on Display.
   * Now show the sidechains of the selected amino acids by clicking on Style >> Side chain >> Stick and color these amino acids by clicking on Color >> Atom.
   * To show the hydrogen bonds and other interactions between the highlighted amino acids click on View >> H-bonds & interactions. In the new window that opens select the types of interactions to view, (e.g. H-bonds, salt bridges), keep the default options and click on Display. The interactions should be shown in dashed lines.
   * Zoom in on the selected residues by clicking on View >> Zoom in selection.

*Box 10: Concept*

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. 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).

Learn more at <https://earth.callutheran.edu/Academic_Programs/Departments/BioDev/omm/jsmolnew/bonding/chymo.html#Topic2>

Q7. What does the R274 side chain interact with? What do you think is important about this interaction? (Examine the neighboring region to answer this question and support your answer with a suitable molecular illustration).

Figure 2B in the George et al., 2004 paper shows the relative orientation of R274 and the phosphothreonine at 309 (see below).

A picture containing text, map

Description automatically generated

Redraw the above figure using the iCn3D tool and show the sidechains of R274, pT309, D275, H196, and S9 (in the GSK3 peptide). Once you have oriented the structure in the above view, you can measure distances between atoms as follows:

* Click on View >> Distance >> Measure – a new window opens with entitled “Measure the distance of …”
* Identify the atoms between which you would like to measure the distance. Click on them while holding the Alt key to select them both. (If you are unable to select both atoms click on one atom with the Alt key pressed and then click on shift + Alt + the second atom. Now click on Display in the “Measure the distance of …” box.
* Note down the distance displayed in the graphics screen.

Q8. Which atoms in R274 and pT309 are closest to each other? What the distance of closest approximation between R274 and pT309? What interactions exist between these atoms? Illustrate your answer with a screenshot of this measurement.

In the proband, the R274 is mutated to His. Examine the side chains of Arg and His shown below and measure distances as described above.

A close up of text on a white background

Description automatically generated

Q9. What is the closest distance of approximation between His and pT309? (Hint: use an equivalent atom in Arg to represent the His atom that would be present in the mutant.). How would the interactions between amino acid 274 and 309 change in the mutant? Include suitable molecular images to support your answer.

Back to the Megan, Jade, and Joanna story …

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When Megan had read through the paper, she was excited that she understood how the single mutation in Akt-2 could result in insulin resistance and diabetes. However, she was also concerned – if the R274H mutation reduced the kinase activity, all signaling molecules downstream of Akt-2 would not be able to pass on the signal to facilitate glucose uptake by cells. In fact, if any of the signaling molecules in the complex insulin signaling pathway was missing or non-functional it could lead to insulin resistance and diabetes. Megan also realized that many of the current diabetes treatment approaches either promote insulin secretion or inject more insulin into the system. Ironically, in the case of insulin resistance, all these approaches would probably not be helpful. For the past few weeks Megan has been wondering – how did they treat the proband and other individuals in their family?

**Part 4: Bypassing the Roadblock**

Two weeks ago, when Megan was walking by the Biochemistry Seminar Announcement board, she stopped as she read the title – “Insulin Resistance and Improvements in Signal Transduction”. Wow! She thought this is exactly what she had been wondering about since she had read the George et al., 2004 paper. She decided to attend that seminar. The speaker, Dr. Laurie Goodyear, was a researcher at Joslin Diabetes Center, Boston, and spoke about the role of physical exercise in reducing blood glucose levels in type 2 diabetes. In this lecture Megan learned about insulin-independent glucose uptake!

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Examine the following simple figure from Dr. Goodyear’s seminar and notice the crosstalk between insulin dependent and insulin independent glucose uptake in skeletal muscle cells.

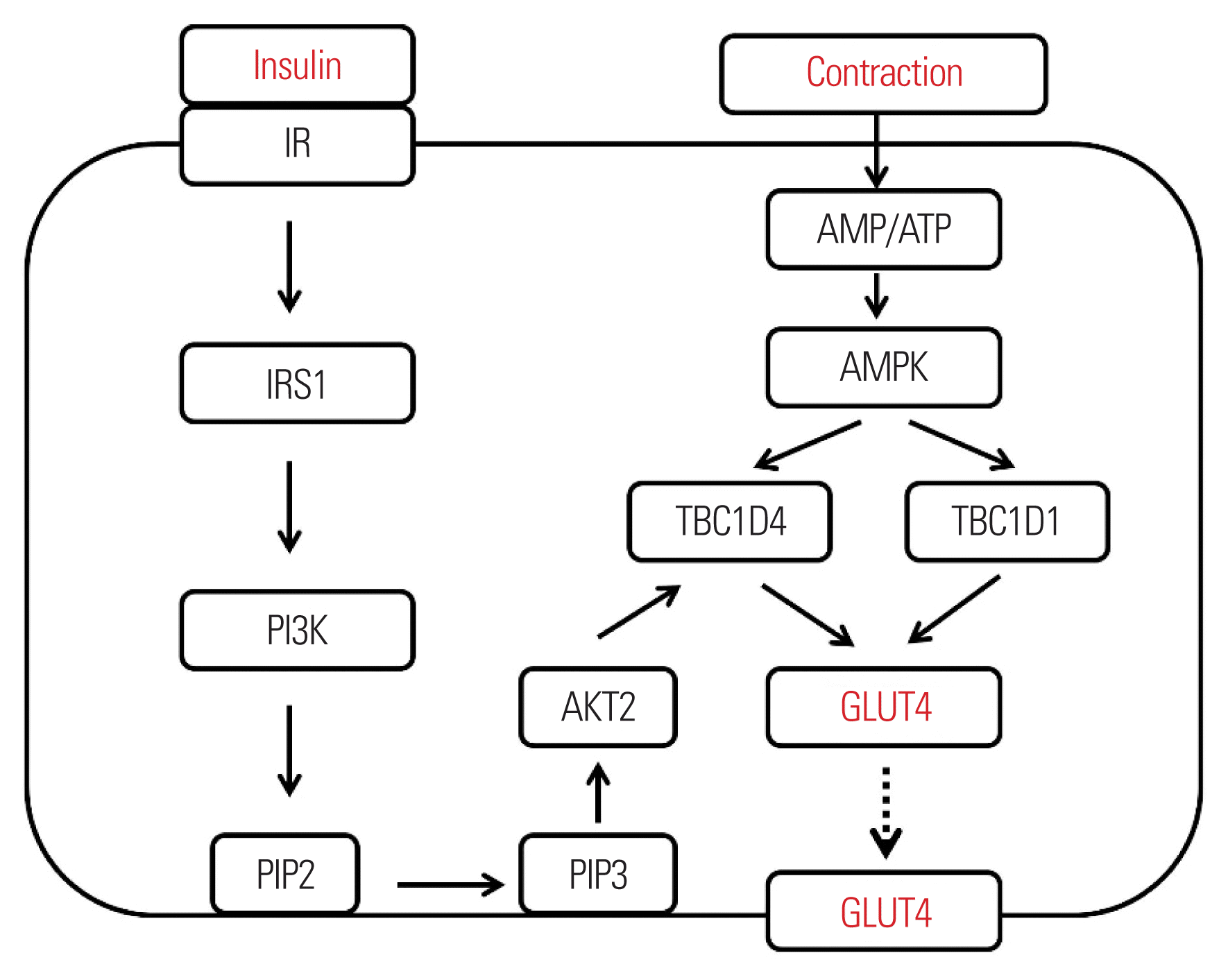


Figure 1. Journal of Obesity & Metabolic Syndrome 2018; 27(3): 150-157. doi: 10.7570/jomes.2018.27.3.150.

In the above figure do you notice that exercise uses up cellular ATP, activates AMP kinase, which in turn acts on TBC1D1 and TBC1D4 to facilitate the transport of GLUT4 receptors to the cell membrane for glucose uptake? So now even when the insulin signaling fails this pathway can be activated!

Megan was really excited and wants to write a letter to Jade to explain all the things that she has found out about insulin resistance, its cause, and treatment approaches.

Q1. Help Megan write 1-2 paragraphs (5-10 sentences) and at least one image to explain insulin resistance and possible ways to manage it.