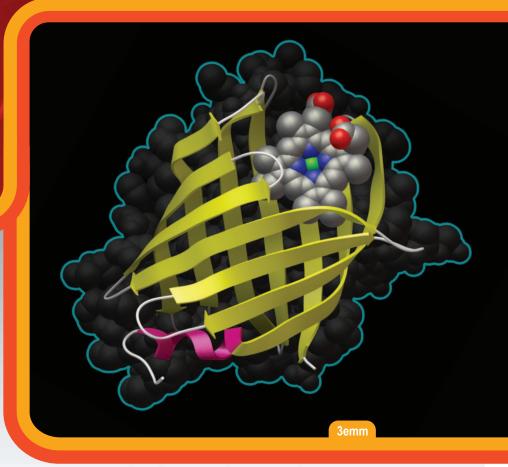
PSI nature StructuralBiologyKnowledgebase





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About the PSI SBKB

To present a broader view of structural biology and structural genomics research, the **PSI Structural Biology Knowledgebase** offers centralized access to the following information from the Protein Structure Initiative and beyond:

- biological annotations
- theoretical models
- all structures in the Protein Data Bank
- protein production protocols
- DNA clones and technologies
- research library
- new research and technical highlights
- news and events calendar



The Protein Structure Initiative Structural Biology Knowledgebase (PSI SBKB, sbkb.org) is a free online resource that enables users to discover how amino acid sequences, 3D structures, and theoretical models help us understand protein function. A single search of the SBKB will provide links to 3D protein structures, pre-built theoretical models, biological annotations, structural genomics target information, protocols, and access to DNA clones. The website offers an easy way to keep abreast of developments by the PSI and more generally in the fields of structural biology and structural genomics.

The **PSI SBKB** is a collaboration between the Protein Structure Initiative (PSI) and Nature Publishing Group (NPG). Funding is provided by the National Institute of General Medical Sciences.

The Protein Structure Initiative

The PSI is a federal, university, and industry effort to dramatically reduce the costs and reduce the time it takes to determine a three-dimensional protein structure. The long-range goal of the PSI is to make the 3D atomic-level structures of most proteins easily obtainable from knowledge of their corresponding DNA sequences.

Nature Publishing Group

NPG is the scientific publishing arm of Macmillan Publishers Ltd. It publishes journals and online databases across the life, physical and applied sciences and, most recently, clinical medicine. Content encompasses daily news from awardwinning journalists, expert opinion, practical methodology, and high impact research and reviews.



ABOUT THIS CALENDAR

The 2012 PSI SBKB calendar is composed of selections from the PSI Featured System and Featured Molecule series, written and illustrated by David Goodsell (The Scripps Research Institute) especially for the SBKB. Each month features a space-filling representation, (like the image below) which shows the overall shape and volume of the biomolecule, a ribbon diagram to show how the amino acid sequence folds into the presented 3D shape, and an explanation of biological and/or biomedical relevance of this protein structure for readers of all ages and backgrounds.

ABOUT THE PSI FEATURED SYSTEM

The PSI Featured System (on the homepage at **sbkb.org**) is a monthly article about one of the many protein systems studied by the PSI high-throughput structural genomics and structural biology efforts. Molecular images are created by the Python Molecular Viewer (**mgltools.scripps.edu**). In addition, the web-version of the PSI Featured System includes an interactive view of the protein structure that allows users to explore the 3D structure on their own.



Nitrobindin

doi:10.3942/psi_sbkb/fm_2010_12

Proteins perform most of the nanoscale tasks inside of cells, but occasionally, they need help from more exotic molecules. For instance, very small molecules like oxygen are difficult to capture, and proteins like hemoglobin use a heme to trap them. Heme is used in many other capacities as well, including the management of electrons and the capture of other gas molecules such as nitric oxide. So, when researchers at CESG discovered a new heme-containing protein in the plant *Arabidopsis*, they were faced with an exciting challenge: what is the heme doing?

HEME EXPOSED

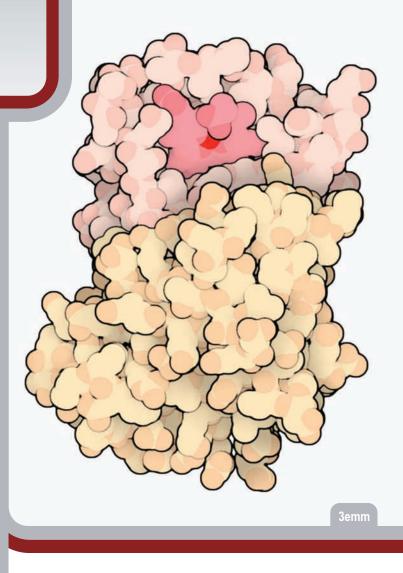
The heme in nitrobindin (PDB entry 3emm, pictured on the cover and at right) is unusual in that the iron atom found in all heme molecules is rather exposed to solvent. In many heme proteins, the heme is buried deep within the protein, with perfectly-placed amino acids guarding access to the iron atom. For instance, globins have a histidine on one side of the heme, which positions the iron in the proper place, and a histidine or glutamine on the other side, leaving just enough room for oxygen to bind. Nitrobindin, on the other hand, has a similar histidine coordinated directly to the iron, but the other side of the iron is free to interact with water. This has an unusual consequence: in the presence of oxygen, the iron atom is rapidly oxidized and shows only a weak interaction with oxygen.

MANAGING NITRIC OXIDE

Testing revealed, however, that the reduced form of the protein binds to nitric oxide (NO) with substantial affinity. This has posed a mystery about the function of the protein. Nitric oxide, in spite of its significant toxicity, is widely used in animal cells as a hormone in particular, in the local control of blood flow. It plays a similar role in plant cells as part of a complex signaling network that decides what to do when cells are infected or wounded. One clue to the function of nitrobindin is provided by the similar NO-binding protein nitrophorin. Nitrophorin is made by blood-sucking insects and used to deliver NO to their victims, where it dilates the blood vessels and provides more blood for the insect. Nitrobindin may play a similar role in plants, providing a way to store NO safely until it is needed.

ANOTHER NITROBINDIN

Structural genomics often acts like a snowball, starting with a central piece of information, then growing around that. Building on the Arabidopsis nitrobindin structure, researchers at the CESG then looked to the human genome and found a similar protein there. The protein THAP4 includes a modified zinc finger, which binds to DNA, as well as a nitrobindin-style heme-binding domain. A recent crystallographic structure of the nitrobindin portion (PDB entry **3ia8**, not shown) revealed a structure very similar to the *Arabidopsis* nitrobindin, with a beautifully symmetrical beta barrel, a hemebinding pocket at one end and a special shape called a 3_{10} helix at the opposite end.



SBKB Quick Fact

The SBKB is updated weekly with new targets, structures, methods, and annotations. Learn about all this, and how to subscribe to RSS feeds and E-alerts, at **sbkb.org**

Bianchetti, C. M. et al. Proteins 78, 917-931 (2010). PDB ID: 3emm

Wendehenne, D. et al. Nitric oxide: a new player in plant signalling and defence responses Curr. Op. Plant Biol. 7, 449-455 (2004).

The Perils of Protein Secretion

doi:10.3942/psi_sbkb/fm_2011_11

Salmonella bacteria are tiny terrorists that infect cells and ultimately destroy them. They don't, however, just kill cells outright. The attack is far more measured, so that the bacteria have time to multiply within the cell before the cell dies. To control this process, *Salmonella* bacteria inject a deadly cocktail of proteins into their targets. These "effector" proteins assist in the entry of bacteria into the cells, they thwart cellular defense systems, and they ultimately destroy the cells when the bacteria have finished with them.

DEADLY NEEDLE

Many of these effector proteins are injected into cells through a "needle complex" through a process known as type III secretion. Structures are available for a few of the many components of this complex, as shown in the top image. In the image, we are looking from the outside of the cell through the middle of the complex. At the center, there is a "needle" protein with a narrow opening, shown in red from PDB entry **2v61**. Because the opening is so small, effector proteins must be unfolded before they are threaded through the hole and into the infected cell. Surrounding the needle several concentric rings of proteins, shown here in blue and green from PDB entries **2y9j** and **2y9k**, that anchor the needle in the bacterial cell wall.

CAREFUL REGULATION

As you can imagine, this process must be carefully regulated, so that the proper effector proteins are injected at the proper time. Researchers at PCSEP are using protein network analysis to uncover the many players involved in this control. By looking at the proteins that are expressed during infection, and comparing these to the bacterial proteins that are expressed at other times, they can identify the proteins specifically involved in secretion, and determine networks of how they interact with one another. By analyzing these networks, they have discovered that many mechanisms come into play, including type III secretion through the needle complex as well as other forms of secretion.

CONTROLLING CELL DEATH

Since *Salmonella* lives and reproduces inside the cells it infects, it needs to control the life and death of the cell. In some cases, such as macrophages, it wants to kill the cell quickly and efficiently, to

hobble the immune system. In other cases, such as epithelial cells, it needs to wait and kill the cell later, when it's ready to escape and spread. The bacterial effector proteins make these decisions, forcing infected cells to die on command. For instance, the SlrP protein of *Salmonella* mimics the E3 ubiquitin ligases. These ligases normally control the disposal of obsolete proteins in our cells by attaching the small protein ubiquitin to them, which marks them for destruction by the proteasome. SlrP hijacks this system, using it instead to destroy essential proteins involved in the cellular immune response.

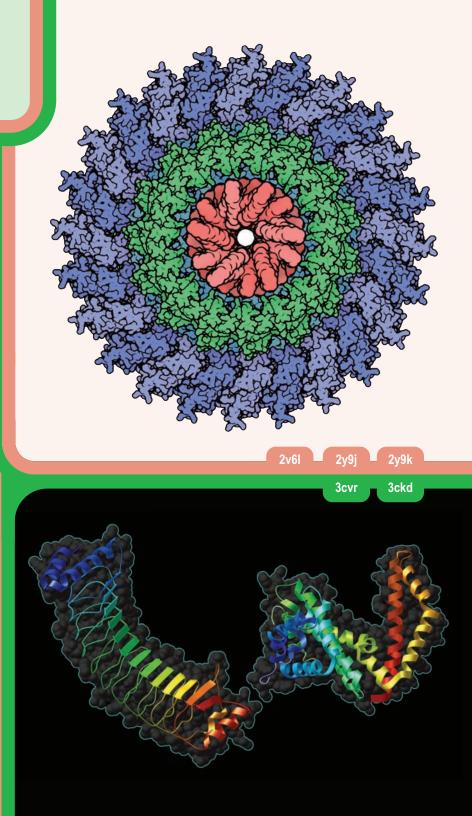
EXPLORING AN EFFECTOR PROTEIN

MCSG researchers are exploring the structures of these bacterial E3 ubiquitin ligases, looking at the SIrP protein of *Salmonella* and the similar protein IpaH from *Shigella*. This is a bit tricky because they are flexible proteins, with two separate domains connected by a short hinge, so PSI researchers had to cut the enzymes into two pieces and solve the structures of each half individually. One half, shown here on the left from PDB entry **3cvr**, recognizes the target protein, and the other half, shown on the right from PDB entry **3ckd**, performs the reaction that connects ubiquitin.

Schraidt, O. & Marlovits, T. C. Three-dimensional model of Salmonella's needle complex at subnanometer resolution. Science 331, 1192-1195 (2011). PDB ID: 2939, 299k Bernal-Bayard, J. & Ramos-Morales, F. Salmonella type III secretion effector SIrP is an E3 ubiquitin ligase for mammalian thioredoxin. J. Biol. Chem. 284, 27587-27595 (2009). Singer, A. U. et al. Structure of the Shigella T3SS effector IpaH defines a new class of E3

ubiquitin ligases. *Nature Struct. Mol. Biol.* **15**, 1293-1301 (2008). **PDB ID: 3ckd** Zhu, Y. *et al.* Structure of a Shigella effector reveals a new class of ubiquitin ligases.

Znu, Y. et al. Structure of a Snigella effector reveals a new class of ubiquitin ligases. *Nat.Struct.Mol.Biol.* **15**, 1302-1308 (2008) **PDB ID: 3cvr**



Deane, J.E. et al. Molecular model of a type III secretion system needle: Implications for host-cell sensing. *Proc.Natl.Acad.Sci.USA* 1030, 12529 (2006) PDB ID: 2v6l Vonn H. et al. Systems analysis of multiple regulator netrurbations allows discovery of

Yoon, H. et al. Systems analysis of multiple regulator perturbations allows discovery of virulence factors in Salmonella. BMC Sys. Biol. 5:100 (2011). McDermott, J. E. et al. Computational prediction of type III and IV secreted effectors

in gram-negative bacteria. Infection and Immunity **79**, 23-32 (2011).

January 2012	SBKB Quick Fact	The SBKB Database is updated weekly with new targets, structures, methods, and annotations. Learn about all this, and how to subscribe to RSS feeds and E-alerts, at
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Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6	7
New Year's Day						
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Pseudouridine Synthase TruA

doi:10.3942/psi_sgkb/fm_2009_11

Evolution is a great tinkerer. Over the course of millions of years, cells have honed and refined their machinery, selecting many refinements on the basic processes. We can see a perfect example of this by looking at transfer RNA, which are built by ribosomes in the traditional way, using the four standard types of nucleotides. But then a host of enzymes modify the nucleotides to form many different exotic structures. The most common modification is an isomerization: a uracil base is removed, flipped around, and reattached through one of its carbon atoms, changing uridine to pseudouridine.

FLIPPED BASES

The change from uridine to pseudouridine is subtle and has a subtle structural effect. The new C-C bond connecting the base to the sugar is more flexible than the typical C-N bond found in canonical nucleotides "bases", however, the pseudouridine ironically makes the RNA strand a bit more rigid. The enhanced rigidity is caused by the new placement of the nitrogen atom. In normal bases the nitrogen atom is used to connect to the sugar, but in pseudouridine it is available to hydrogen bond to water. This water then can form hydrogen bonds with the nearby phosphate atoms, rigidifying the backbone and ultimately enhancing the stacking of bases. This is thought to be the major benefit of pseudouridine: it adds a little extra rigidity to regions of the RNA that need to have a defined structure.

SWITCH TO PSEUDOURIDINE

Researchers at CSMP have revealed how *Escherichia coli* cells modify uridine nucleotides in the anticodon stem loop of transfer RNA. TruA is a pseudouridine synthase that specializes in three positions in the tRNA, positions 38, 39, and 40. These positions are in the critical base-paired region adjacent to the anticodon. The enzyme is a dimer of two identical subunits, which embraces both the 38-40 region of the tRNA and regions farther up the molecule. The enzyme acts on 17 different tRNA molecules in the bacteria cell. It appears to prefer tRNA molecules that are flexible, passing up ones that already have rigid anticodon stem loops. In this way,

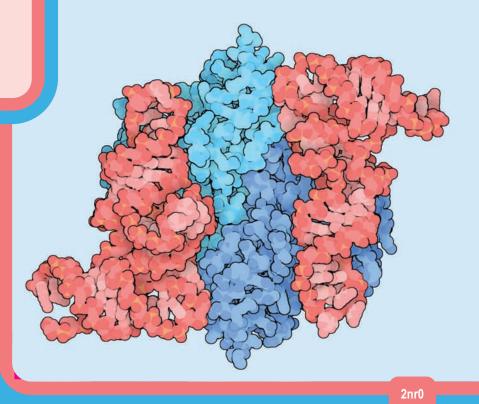
the enzyme helps the cell fine tune its tRNA, making them rigid but not too rigid for optimal function.

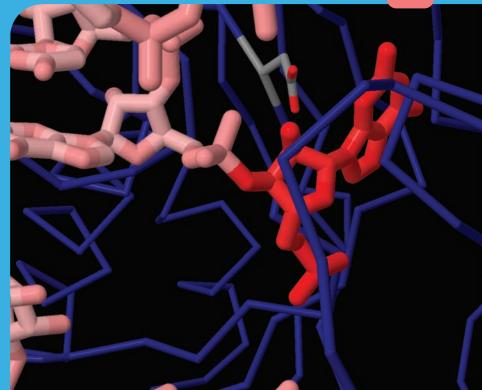
FLEXIBLE EMBRACE AND A FLIPPED OUT BASE

The crystal structures show the structural basis for TruA's affinity for flexible tRNA molecules. Three different crystals of the enzyme in complex with two different forms of the leucine tRNA where obtained. Comparing the different structures, the tRNA shows a large range of motion. In several structures, a loop is bent outwards away from the enzyme. These structures highlight the importance of a key arginine amino acid for finding the base and pulling it into the active site. Several of the structures showed a conformation that is later in the process of acting on the base, with the loop folding deeper into the active site. In one of these structures, shown here from PDB entry 2nr0, a base is flipped out of the normal base pair and inserted into the active site. In this case it is guanine 39, so the structure is an abortive complex, since the enzyme does not make any changes to guanine bases. But it gives an idea of what might happen when the enzyme shifts to place a uridine in the active site. A conserved aspartate (grey) is there, ready to extract and flip the base.

Hur, S. & Stroud, R. M. How U38, 39, and 40 of many tRNAs become the targets for pseudouridylation by TruA. *Mol. Cell* 26, 189-203 (2007). PDB ID: 2nr0

Hur, S. et al. Substrate recognition by RNA 5-methyluridine methyltransferases and pseudouridine synthases: a structural perspective. J. Biol. Chem. 281, 38969-38973 (2006).Hamma, T. & Ferre-D'Amare Pseudouridine synthases. Chem. Biol. 13, 1125-1135 (2006).Charette, M. & Gray, M. W. Pseudouridine in RNA: what, where, how, and why. IUBMB Life 49, 341-351 (2000).





February 2012	SBKB Quick Fact	The Protein Structure Initiative invites scientists to suggest proteins for structural determination. Make your nominations now at:
		sbkb.org/cnt/

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
January 2012 S M T W R F S 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31	11 12 13 14 15 16 17		1	2	3	4
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19	20 Presidents' Day (US)	21	22	23	24	25
26	27	28	29			

Hemolysin BL

doi:10.3942/psi_sgkb/fm_2010_1

Bacteria are master weapon makers. They must compete with other microorganisms for resources and they live in constant danger of being eaten and digested by larger animals, so many bacteria build powerful toxins to protect themselves. These toxins come in all shapes and sizes and seemingly attack every possible target in their foes. Three closely-related *Bacillus* species exemplify this diversity. *Bacillus anthracis*, the bacterium that causes anthrax, builds a three-part toxin that enters into cells and attacks the signaling apparatus, confounding the signals needed to orchestrate communication within the cell. The similar bacterium *Bacillus thuringiensis* builds a toxin that attacks insect cells, and is now sprayed on plants to act as a living insecticide. *Bacillus cereus* builds a different three-component toxin that attacks the cell membrane of intestinal cells, causing the miserable symptoms of food poisoning as our bodies try to flush it out.

A PERVASIVE PEST

Bacillus cereus is a bacterial jack-of-all-trades. Seemingly, it's happy almost anywhere. It is common in soil, where it grows and reproduces. When times get tough, it forms a weather-resistant spore and waits for better conditions. These spores find their way onto food of all sorts, and from there into our digestive system. The bacterium can also live in the intestine, along with the many other species of bacteria that inhabit us. Some strains of *Bacillus cereus*, however, build toxins like hemolysin BL that attack intestinal cells. These strains are thought to be a widespread cause of food poisoning, but this has been hard to quantify since the symptoms are mild and pass quickly, and often are not reported to doctors.

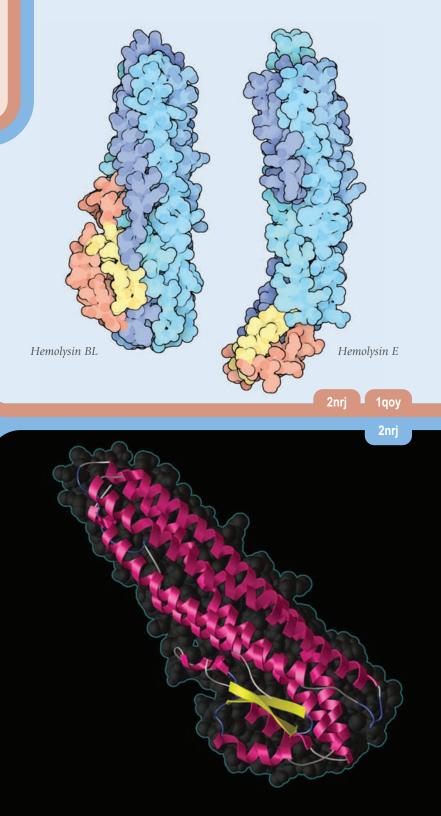
PORE-FORMING TOXINS

Hemolysin BL, like many other bacterial toxins, forms a pore through the membrane of cells, allowing ions and small molecules to leak out. Creating a pore with a soluble protein is a tricky proposition. The protein must be soluble enough that it can be built and exported from the bacterial cell, but then it must create a pore within the hydrophobic environment of the membrane. The solution used by many toxins is a switchblade mechanism. The portion of the toxin that penetrates the membrane is folded inside the soluble form of the protein, waiting to be deployed when the target cell is found.

B-COMPONENT

Researchers at NYSGXRC have solved the structure of hemolysin BL toxin in its soluble state, available in PDB entry 2nrj. In this form, the toxin is ready to seek out a target cell and build its deadly pore. Most of the protein chain forms a large bundle of alpha helices. A small hairpin loop, colored yellow here, is thought to be the penetration mechanism. When it finds its target cell, this loop will unfold and enter the membrane. Then, as several copies of the toxin bind side-by-side, a pore is formed. The active toxin is actually composed of three separate components: the B subunit shown here, and two L subunits that assist with the construction of the pore. The similar hemolysin E from *Escherichia coli* cells (entry 1qoy at the PDB) shows one possible step in this switchblade action, where the small domain that includes the penetration loop (yellow) has opened up before binding.

Wallace, A.J. et al. E. coli hemolysin E (HlyE, ClyA, SheA): X-ray crystal structure of the toxin and observation of membrane pores by electron microscopy. *Cell(Cambridge,Mass.*) 100, 265 (2000). PDB ID 1qoy



Madegowda, M. et al. X-ray crystal structure of the B component of Hemolysin BL from Bacillus cereus. Proteins 71, 534-540 (2008).

Schwartz, T., & Blobel, G., Structural basis for the function of the beta subunit of the eukaryotic signal recognition particle receptor. *Cell(Cambridge,Mass.*) 112, 793-803 (2003). PDB ID 2nrj

Stenfors Arnesen, L. P. et al. From soil to gut: Bacillus cereus and its food poisoning toxins. FEMS Microbiol. Rev. 32, 579-606 (2008).

March 2012

The Structural Biology Update highlights recently released protein structures and techniques, news, and events to keep you informed of what's going on in the field. Visit this month's update at:

sbkb.org/update/

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
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Daylight Saving Time begins in USA						St. Patrick's Day
18	19	20 Spring begins	21	22	23	24
25 Daylight Saving Time begins in Europe	26	27	28	29	30	31

Exploring the Secretome of Gut Bacteria

doi:10.3942/psi_sbkb/fm_2011_09

We often think of bacteria as our enemies, as something we need to fight with antiseptics and antibiotics. While this may be true for certain rogue bacteria, like the ones that cause food poisoning or cholera, we actually rely on the rich bacterial communities that surround and inhabit us. Bacteria are essential parts of our environment, found in nearly every corner of the world where they break down dead organisms and make their resources available for new growth. Our own bodies also rely on a diverse collection of bacteria that live on every inch of our body: in our digestive system, on our skin and in our mouth. Gut bacteria break down difficult molecules in our diet and provide many essential cofactors and vitamins. In other parts of our body, they maintain healthy pH, simulate the immune system, and even help protect us from infection by pathogenic bacteria.

A SWEET DEAL

Researchers at JCSG are using structural genomics to explore our symbiotic relationship the bacteria in our gut, including one of the most prevalent species: *Bacteriodes thetaiotaomicron*. This species and its relatives are important, among other things, for the digestion of complex carbohydrates in our diet. These bacteria make several hundred enzymes and transporters involved in carbohydrate metabolism, so they are well equipped for their task of breaking these into simpler sugar, for use by the bacterium and by us. This role is significant: a study showed that germ-free mice need to eat roughly 30% more food than mice that have a healthy crop of bacteria.

MUTUAL BENEFIT

The bacteria in our gut have developed a mutuallybeneficial truce with their hosts after millennia of evolution. Researchers at JCSG are exploring the molecules that mediate this truce, looking at the diverse collection of proteins that are secreted by intestinal bacteria to protect themselves and gather the nutrients they need to live. This truce requires a delicate balance between our need to protect ourselves from life-threatening infection, and each bacterium's need to find a suitable niche to live.

MEMBRANE ATTACK COMPLEXES

The recent structure of Bth-MACPF (membraneattack complex/perforin) from the JCSG, shown here from PDB entry 3kk7, is opening new windows on the molecular mechanisms that mediate this truce. The structure revealed that it is similar to a class of defensive proteins that poke holes through cell membranes of pathogenic bacteria, such as human complement protein C8alpha. Using a tricky structural switch (colored in red), the complement protein helps to form pores in bacterial membranes, and it is one of the mechanisms that we have to fight bacterial infection in our blood.

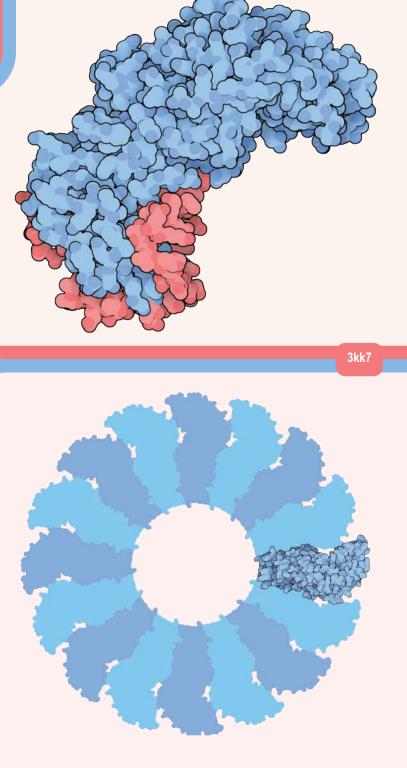
FRIEND OR FOE?

The bacterial MACPF presumably forms similar pores, based on the similarity to our pore-forming molecules. However, the function of the bacterial MACPF pore is still a mystery. It doesn't seem to attack our own cells; our cell membranes are much more complex than bacterial cell membranes, and besides, that would break the truce and flag the bacterium as a pathogen. JCSG researchers have come up with a few ideas for how it might function in a less aggressive way: it may be used for transport of molecules across cell membranes, or as part of a defense against pathogenic bacteria, or even as a method to disarm our own defensive pore-forming molecules.

Hadders, P. et al. Structure of C8alpha-MACPF reveals mechanism of membrane attack in complement immune defense. Science 317, 1552-1554 (2007).

Zocco, M. A. et al. Bacteriodes thetaiotaomicron in the gut: molecular aspects of their interaction. Digestive Liver Disease 39, 707-712 (2007).

Comstock, L. E. & Coyne, M. J. Bacteriodes thetaiotaomicron: a dynamic, niche- adapted human symbiont. *BioEssays* 25, 926-929 (2003).



Xu, Q. et al. Structure of a membrane-attack complex/perforin (MACPF) family protein from the human gut symbiont Bacteriodes thetaiotaomicron. Acta Cryst. F66, 1297-1305 (2010). PDB ID 3kk7

April 2012

SBKB Quick Fact

The PSI Sequence Comparison and Analysis tool finds similar protein structures, protein targets, and theoretical models, and also calculates biophysical parameters. Improve your protein design now at:

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Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
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Antibiotics and Ribosome Function

doi:10.3942/psi_sgkb/fm_2010_3

Antibiotics are often discovered in nature, where they are lethal weapons in the fight between different organisms. The aminoglycoside antibiotics, such as streptomycin, are made by some bacteria to protect themselves from competing bacteria. They are particularly effective because they are specific: they attack bacterial ribosomes, corrupting protein synthesis in the bacterium, but they don't attack the ribosomes of many other organisms including our own ribosomes. This makes them perfect for use as antibiotic drugs–they will control a bacterial infection but have few side effects on our own cells.

MAGIC BULLETS

As is often the case, streptomycin and other aminoglycoside antibiotics were discovered through their ability to kill bacteria, and then scientists had to figure out how they worked. These antibiotics have several effects on bacterial protein synthesis. They effect the way that messenger RNA is read, causing errors in translation and inhibiting the orderly stepping of the ribosome along the mRNA strand. They also cause problems at the end of protein synthesis, blocking the recycling of ribosomes after they are finished making a protein. New structures, solved in collaboration with researchers at CSMP, revealed the atomic basis of both of these effects.

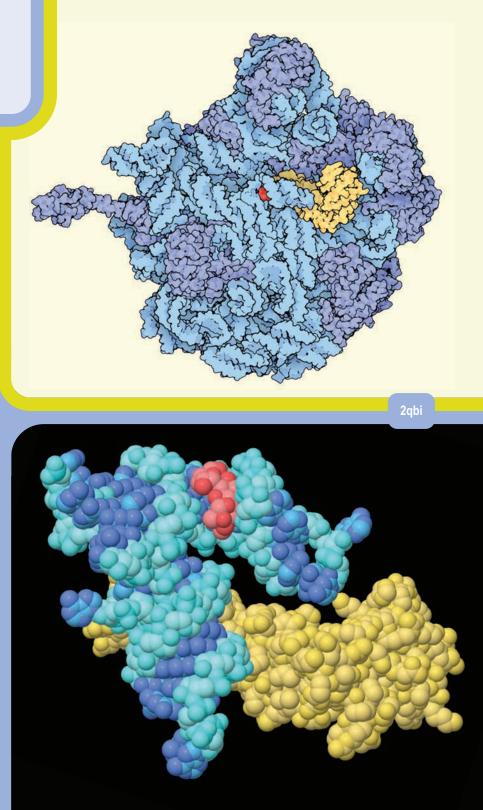
ANTIBIOTIC ACTION

Structures of whole ribosomes with the antibiotic drugs neomycin, gentamycin and paromomycin have shown that there are two different binding sites. One site is in the small ribosomal subunit. The drug wedges into one of the ribosomal RNA helices at the site where the mRNA is matched with the appropriate tRNA, blocking the subtle motions needed for decoding and translocation. The second site is on the large ribosomal subunit, binding to a small loop of ribosomal RNA that interacts with ribosomal recycling factor (RRF), the protein that assists the recycling of ribosomes.

HOW TO STOP RECYCLING

The structure shown here (PDB entry 2qbi) shows the complex of a ribosome (blue) with RRF (yellow) and the antibiotic neomycin (red). The small subunit of the ribosome has been removed to show the interaction, which is normally buried deep inside the intact ribosome. RRF interacts with a small loop in the ribosome, which is important in the interaction between the large and small subunits. By comparing this structure with a similar structure of the ribosome and RRF without the drug (PDB entry 2qbe), researchers have discovered that the antibiotic distorts the structure of this loop, freezing the motions that are necessary for recycling.

Borovinshaya, M. A. et al. Structural basis for aminoglycoside inhibition of bacterial ribosome recycling. Nature Structural and Molecular Biology 14, 727-732 (2007). PDB ID 2qbi



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Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
April 2012 S M T W R F S 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30	June 2012 S M T W R F S 0 0 1 2 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30	1	2	3	4	5
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13 Mother's Day	14	15	16	17	18	19
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27	28 Memorial Day (US)	29	30	31		

Mre11 Nuclease

doi:10.3942/psi_sgkb/fm_2010_5

All living things on the Earth store their genetic information in long strands of DNA. These strands of DNA are delicate, and may be damaged in many ways, so all cells face the same problem: how to protect their DNA and repair it if gets damaged. Breaks of the entire double helix, breaking both strands at once, are the most dangerous problems that happen to DNA, and most cells have two elaborate repair mechanisms to correct them. Double-strand breaks are more common than you might imagine: they can be caused by outside dangers such as radiation or chemicals, but they also happen by accident during the normal processes of replication and recombination. Of course, if they are left unfixed, they are disastrous, destroying genes and corrupting the integrity of chromosomes.

CAREFUL REPAIRS

Mre11 is at the heart of one of the major processes that fixes double-strand breaks in DNA. This method is called homologous recombination, because it relies on having at least two similar copies of the genome in the cell. It uses one copy of the genome as a template to reconstruct the broken copy. Because it uses an intact DNA to guide the repair, it is very accurate. Mre11 finds the broken ends of the DNA and gets this whole process started.

PREPARING BROKEN DNA

Mre11, shown here from PDB entries **2q8u** and **3dsc**, is composed of two identical subunits, which associate to form a complex with a groove down the center. The two arms of the complex (extending to right and left here) bind to DNA, positioning the broken DNA strands (the short pieces of DNA used for the structure analysis are shown in red and yellow). The nuclease domains in the center of the protein trim the ends of the DNA and make them ready for repair. Mre11 acts as part of a larger complex of proteins, including one called Rad50, that forms a tether between the broken strands and the rest of the chromosomes.

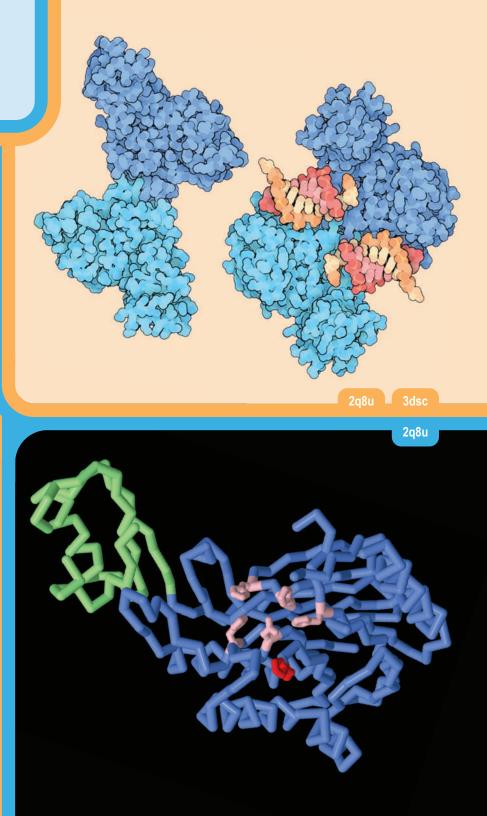
DISCOVERING A NEW MRE11

Researchers at JCSG have solved the structure of Mre11 from the eubacterium *Thermatoga*

maritima, as part of their large structural genomics effort to determine the structure of all proteins from this organism. The structure was instrumental in determining the function of the protein. It was postulated to be a nuclease based on its sequence, but its identification as Mre11 nuclease was only made after the structure was solved, since its sequence is quite different from the sequences of Mre11 nucleases from organisms in other kingdoms. Comparison of the Thermatoga enzyme with the one from the archaeon Pyrococcus furiosus showed that they have similar domain structures and active sites, but differences in their fine structures may cause them to interact differently with particular types of damaged DNA. By comparing these two structures, researchers will be able to pinpoint the structural features that are important for DNA recognition and interaction of Mre11 with its partners in homologous recombination.

Williams, R. S. et al. Mre11 dimers coordinate DNA end bridging and nuclease processing in double-strand-break repair. Cell 135, 97-109 (2008). PDB ID: 3dsc

Williams, R. S. et al. Mre11-Rad50-Nbs1 is a keystone complex connecting DNA repair machinery, double-strand break signaling, and the chromatin template. *Biochem. Cell Biol.* 85, 509-520 (2007).



Das, D. *et al.* Crystal structure of the first eubacterial Mre11 nuclease reveals novel features that may discriminate substrates during DNA repair. *J. Mol. Biol.* **397**(3): 647– 663 (2010). PDB ID: 2**4%u**

June 2012

The Protein Models Portal, a module of the SBKB, stores millions of pre-computed model structures. You can search for models through the SBKB search box or visit the Models Portal directly at

www.proteinmodelportal.org

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17 Father's Day	18	19	20	21 Summer begins	22	23
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Bacterial Armor

doi:10.3942/psi_sbkb/fm_2011_10

Bacteria are found in nearly every corner of the world, evolving unique mechanisms to survive in their different environments. This diversity is apparent when we look at the cell walls of bacteria and their simpler cousins, the archaea. Some decorate their surfaces with a sticky layer of polysaccharide chains, sometimes so thick that it forms a protective capsule. Others use networks of cross-linked polysaccharides and peptides to brace their membranes. Many bacteria also surround themselves with a coat of protein armor, composed of a paracrystalline array of "surface layer proteins." In the case of archaebacteria, this protein coat is the often the primary structure that surrounds and shapes the cell.

SURFACE LAYER PROTEINS

On a typical bacterium, half a million surface layer proteins associate side-by-side to form a continuous shell that encloses the cell. On the inside of the shell, they bind to sugar chains on the cell surface, or in the case of archaebacteria, interact directly with the membrane. This sturdy shell has many advantages for the cell: it provides protection, and it can also assist in the gathering of nutrients and attachment to targets in the environment.

SLH DOMAINS

Most bacterial surface layer proteins contain SLH (surface layer homology) domains that bind to sugar chains on the cell surface. Researchers at MCSG have solved the first structure of bacterial SLH domains, from the bacterium that causes anthrax, shown here from PDB entry **3pyw**. The structure includes three neighboring SLH domains, which together form a triangular protein. The sugar chains are thought to bind in the grooves along the three sides. The protein also includes an additional domain, removed for this structural analysis, that interacts with other copies of the protein to form the shell.

DIVERSE APPROACHES

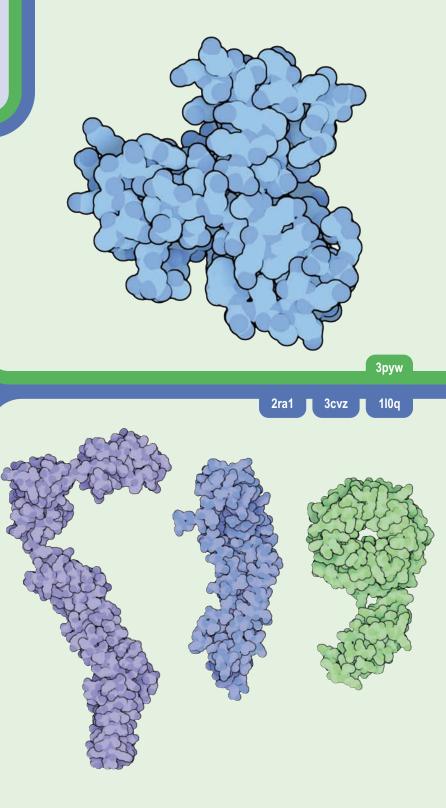
SLH domains, however, are not the only way to create a surface layer: other bacteria use alternative approaches. Examples from two bacteria, *Geobacillus stearothermophilus* (PDB ID **2ra1**), and *Clostridium difficile* (PDB ID **3cvz**), and one from the archaebacterium *Methanosarcina mazei* (PDB entry **1l0q**) are shown at right. As with

the SLH structure from MCSG, these structures include only a portion of the surface layer protein for crystallization and structure determination. They all have completely different shapes and sizes, and if you compare these structures at the RCSB Protein Data Bank you will find that they have entirely different folds.

BUILDING ON NATURE

Surface layer proteins are interesting for several reasons. Since they are the primary barrier from the environment for many bacteria, they are intimately involved in the interaction of bacteria with their hosts. They mediate the flow of nutrients and may help with the attachment, and ultimate virulence, of pathogenic bacteria. SLH domains are also commonly used to attach other proteins to bacterial cell surfaces, so a structural understanding of surface layer proteins will allow modeling of other cell surface proteins. Surface layer proteins have also provided a source of inspiration for nanotech engineers. Since they are working examples of self-assembling nanoscale architecture, they are being used as a model for design of custom nanostructures.

Jing, H. et al. Archaeal surface layer proteins contain beta propeller, PKD, and beta helix domains and are related to metazoan cell surface proteins. *Structure* 10, 1453-1464 PDB ID 2002). PDB ID 100q



Kern, J. et al. Structure of surface layer homology (SLH) domains from Bacillus anthracis surface array protein. J. Biol. Chem. 286, 26042-26049 (2011). PDB ID 3pyw Schuster, B & Sleytr, U.B. Composite 5-layer lipid structure. J. Struct. Biol. 168, 207-216 (2009). Engelhardt, H. Are S-layers exoskeletons? The basic function of protein surface layers revisited. J. Struct. Biol. 160, 115-124 (2007).

Pavkov, T. et al. The structure and binding behavior of the bacterial cell surface layer protein SbsC. Structure 16, 1226-1237 (2008) PDB ID: 2ra1

Fagan, R.P. et al. Structural insights into the molecular organization of the S-layer from Clostridium difficile. *Mol.Microbiol.* 71, 1308-1322 (2009). PDB ID 3cvz

July 2012

SBKB Quick Fact

The PSI:Biology Network is made up of 25 Centers and partnerships using structural biology to answer biological questions. Their structures have been selected for this calendar. Read more at

sbkb.org/kb/psi_centers.html

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6	7
			Independence Day (US)			
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Superbugs and Antibiotic Resistance

doi:10.3942/psi_sbkb/fm_2011_12

Antibiotics were used as weapons to fight bacteria long before Alexander Fleming discovered penicillin. Natural antibiotics like penicillin are made by fungi and other organisms to protect themselves, and as you might expect, bacteria have found many ways to avoid these protections. For instance, beta-lactamases, enzymes that break a key bond in penicillin, were discovered in antibiotic-resistant bacteria before penicillin was ever used in the clinic. However, our widespread use of antibiotics has escalated the battle, leading to the rise of "superbugs" that are resistant to most of the currently known antibiotics.

ANTI-ANTIBIOTICS

NDM-1 (New Delhi metallo-beta-lactamase, shown here on the top from PDB entry 3sfp), is a recent development in this battle. It is an enzyme that destroys almost all known beta-lactam antibiotics, including familiar antibiotics like penicillin as well as specialized carbapenem antibiotics that were specifically designed to fight resistance. To make things worse, the gene for this enzyme is readily traded between bacteria in a plasmid that includes other anti-antibiotic weapons, including enzymes that break down antibiotics like erythromycin and chloramphenicol and a special pump that ejects antibiotics out of bacterial cells.

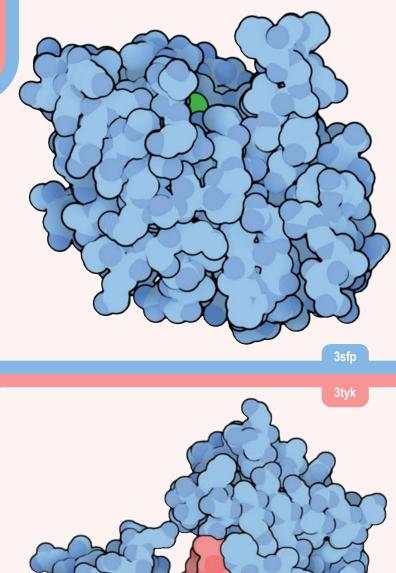
DESTROYING DRUGS

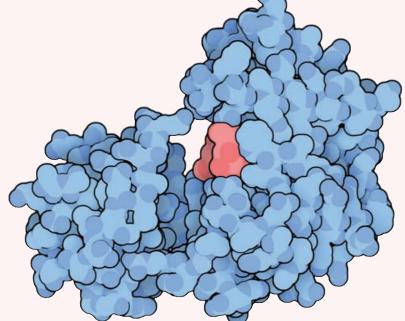
As with many other enzymes involved in antibiotic resistance, NDM-1 modifies antibiotics, rendering them ineffective. Some of these enzymes, such as APH(4)-Ia (shown on the bottom from PDB entry 3tyk) attach bulky groups like phosphates or nucleotides to the drug, making them too big to bind to their bacterial targets. Others, like NDM-1, break bonds in the antibiotic, destroying its ability to form a covalent bond to the target. The structure of NDM-1 revealed the details of the active site, including the location of the catalytic zinc ions and a flexible loop that may be involved in the ability of the enzyme to attach a wide variety of drugs. NDM-1 uses two zinc ions in its cleavage reaction, that activate a water molecule and stabilize an intermediate form of the antibiotic,

making sure that the reaction proceeds smoothly. NDM-1 is also surprisingly effective against many different antibiotics. Structures of NDM-1 from the PSI give an explanation: the active site is much larger than the active sites of similar enzymes. Also, by solving many structures in slightly different states, it was observed that the enzyme is quite flexible, which may be important for accommodating targets of different sizes and shapes.

A CONTINUING BATTLE

Of course, researchers are fighting back and devising new ways to block bacterial resistance. Because of its critical importance in this battle, NDM-1 was chosen as a target by the PSI Biology Partnership MBTI and the structure was solved by their high-throughput partner MCSG. As with all PSI structures, the atomic coordinates are released quickly, providing the information needed to design new compounds to block its action. This would allow a two-pronged treatment that would include a traditional beta-lactam antibiotic to block cell wall synthesis and ultimately kill the bacteria, along with a second drug to thwart NDM-1 and protect the antibiotic.





Kim, Y. *et al.* Structure of apo- and monometalated forms of NDM-1 - a highly potent carbapenem-hydrolyzing metallo-beta-lactamase. *PLoS One* 6, e24621 (2011). PDB ID 3sfp

Stogios, P. J. et al. Structure and function of APH(4)-Ia, a hygromycin B resistance enzyme. J. Biol. Chem. 286, 1966-1975 (2011). PDB ID 3tyk

Moellering, R. C. NDM-1 - a cause for worldwide concern. New Engl. J. Med. 363, 2377-2379 (2010).

August 2012

The PSI Technology Portal provides access to the technologies catalyzed by the PSI research efforts. This information includes documentation, availability, center contacts and licensing terms. Read more at

technology.sbkb.org

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Zinc Transporter ZntB

doi:10.3942/psi_sgkb/fm_2010_7

Zinc is an essential component of many cellular processes. A typical bacterial cell may contain 100,000 zinc ions, and our cells have a thousand times more than this. Zinc is unique among the common transition metals. Unlike iron, nickel and cobalt, it is not redox active, so it does not participate in dangerous reactions with oxygen. Its fully-filled "d" electron shell also makes it relatively promiscuous in its interaction with ligands–it coordinates with sulfur, nitrogen and oxygen atoms in protein sidechains, and has little preference for particular geometries of interaction. Because of these properties, it is widely used both to stabilize protein structure, as in zinc finger proteins, and as an active component in catalysis, as in Cu,Zn superoxide dismutase.

CAREFUL CONTROL

Zinc is a cellular paradox: it plays an essential role in cells, but free zinc ions are highly toxic, attacking cellular machinery. Because of this, zinc levels in the cell are carefully regulated, ensuring that there is just enough for the necessary structural and catalytic roles, but not enough to pose a danger. The level of zinc is controlled by a diverse collection of pumps and channels that ferry zinc ions in and out of the cell. Our genome contains at least two dozen zinc transporters to fit the needs of different types of cells.

FUNNELING ZINC

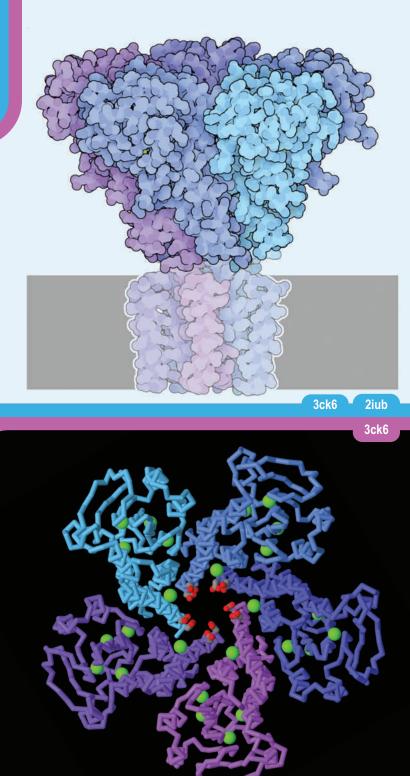
The ZntB zinc transporter controls the flow of zinc out of bacterial cells. It is a funnel-shaped protein composed of five identical subunits, that together form a pore through the membrane. The structure of the intracellular domain was solved by researchers at MCSG, available in PDB entry **3ck**6. The smaller portion that crosses the cell membrane was not included in the structure, and is shown here in lighter colors based on the similar magnesium transporter CorA, PDB entry **2iub**.

STRUCTURE AND FUNCTION

The structure of ZntB revealed several functional features of the transporter. While solving the structure, five localized peaks of electron density were discovered in each of the subunits. After careful study using anomalous diffraction, it turned out that the peaks were not zinc ions, but rather, a collection of chloride ions (green spheres, bottom). Analysis of electrostatics suggests that these chloride ions tune the properties of the funnel, neutralizing positivelycharged amino acids just enough to favor passage of zinc ions rather than monovalent ions like sodium and potassium. The structure also revealed two rings of acidic amino acids at the base of the funnel, which may be important for stripping water molecules off of zinc ions before they are transported.

Tan, K. et al. Structure and electrostatic property of cytoplasmic domain of ZntB transporter. Protein Science 18, 2043-2052 (2009). PDB ID 3ck6

Eide, D. J. Zinc transporters and the cellular trafficking of zinc. *Biochimica et Biophysica Acta* 1762, 711-722 (2006).



Berg, J. M. and Shi, Y. The galvanization of biology: a growing appreciation for the roles of zinc. *Science* 271, 1081-1085 (1996).

Eshaghi, S. et al. Crystal structure of a divalent metal ion transporter CorA at 2.9 angstrom resolution. Science 313, 354 (2006) PDB ID 2iub

September 2012

TargetTrack tracks the progress of protein targets selected for structural determination by over 25 structural genomics centers worldwide. You can search for target information through the SBKB search box or visit TargetTrack directly at

sbkb.org/tt/

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
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30			Yom Kippur			

Rb Tumor Suppressor and Cancer

doi:10.3942/psi_sbkb/fm_2011_08

One of the overarching goals of structural genomics is to characterize the structure and function of entire systems of proteins. This is particularly useful in the study of cancer, since the transformation of normal cells into cancer cells requires the coordinated corruption of many cellular systems, overcoming the many natural protections built into our cells. Researchers at the NESG are studying these connections in whole and in detail. First, they have created the Human Cancer Protein Interaction Network (HCPIN), a resource that gathers data on proteins that are implicated in cancer and their interactions with one another. This network is populated with atomic structures when available and homology models when necessary. Then, NESG researchers have identified key targets in the network for further structural study in cases where no suitable structural information is available.

CENTRAL HUBS

By looking at the many interactions between these proteins, NESG researchers have identified important "hub" proteins, which interact with and control a large collection of other proteins. The retinoblastoma protein (Rb) is one of these hub proteins. It was the first tumor suppressor protein that was discovered, through genetic analysis of individuals who all suffered from a similar form of retinal cancer. As a hub protein, Rb plays a central role in controlling the growth of cells, by deciding when cells are allowed to divide. In cancer cells, Rb is often mutated to destroy its function, allowing the cancer cells to divide without limits.

RB TUMOR SUPPRESSOR

Rb is composed of several domains, each with a specific function, connected by flexible linkers. At the center is a distinctive "pocket" domain, seen in the center of the bottom panel in PDB entry 1gux. It binds to the motif LxCxE, shown here in green, which is found in many of its interaction partners. The C-terminal domain binds to the transcription factor E2F, removing it from the genes involved in cell division. Rb is also controlled by phosphorylation: by adding phosphate groups to the protein, it can't bind to E2F and the genes that control cell division are expressed.

RBBP9

As seen in the network map in the top panel, Rb interacts with many proteins, which together weigh many different signals reaching the cell to decide if it should divide or not. NESG researchers have solved the structure of one of these proteins, shown here from PDB entry 2qs9, identifying the LxCxE motif and also discovering a serine protease active site. Further study has revealed that RB Binding Protein 9 (RBBP9) is important in the connection between Rb and signals from another partner TGF-beta. Surprisingly, the LxCxE motif is bound inside the protein in this crystallographic structure, so the protein must either rearrange a bit to interact with Rb, or interact through a previously unseen mechanism.

RBBP7

Rb, as a major hub of action, also has other functions that don't lead directly to control of the transcription factor E2F. This includes interactions with proteins that control the packaging of DNA into nucleosomes. RBBP7, also known as RbAp46, is an example included in the HCPIN network for Rb. It acts as a histone chaperone that guides the addition of acetyl group to histones. PDB entry **3cfs** includes the protein with a small segment of histone H4.

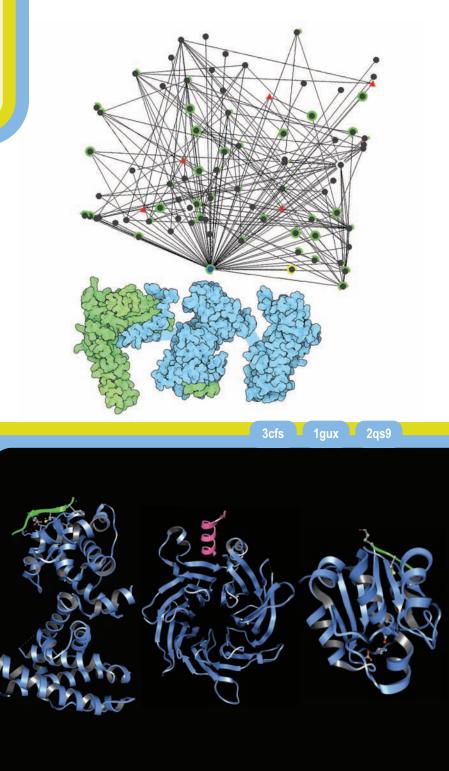
Shields, D. S. et al. RBBP9: A tumor-associated serine hydrolase activity required for pancreatic neoplasia. Proc. Natl. Acad. Sci. USA 107, 2189-2194 (2010).

Burkhart, D. L. & Sage, J. Cellular mechanisms of tumor suppression by the retinoblastoma gene. *Nature Rev. Cancer* 8, 671-682 (2008).

Huang, Y. J. et al. Targeting the Human Cancer Protein Interaction Network by structural genomics. Mol. Cell. Proteomics 7.10, 2048-2060 (2008).

Murzina, N. V. et al. Structural basis for the recognition of histone H4 by the histonechaperone RbAp46. Structure 16, 1077-1085 (2008). PDB ID 3csf

Lee, J. O. et al. Structure of the retinoblastoma tumor-suppressor pocket domain bound to a peptide from HPV E7. Nature 391, 859-865 (1998). PDB ID 1gux



Vorobiev, S. M. et al. Crystal structure of human retinoblastoma binding protein 9. Proteins 74, 526-529 (2009). PDB ID 2qs9

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Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
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CXCR4

doi:10.3942/psi_sbkb/fm_2011_01

The G protein-coupled receptor (GPCR) community is suffering from an embarrassment of riches. For many years, structure-based studies relied on atomic structures of rhodopsin, and research was forced to extrapolate from these using homology models. But in the past few years, PSI researchers have revolutionized the field with new structures and new insights. A collection of five structures of CXCR4, solved by a team of researchers at the PSI GPCR and CHSAM network, is the most recent installment in this exciting story.

SIGNALING IN HEALTH AND DISEASE

CXCR4 is a chemokine receptor that regulates the migration of cells in the immune system. Chemokine receptors typically interact with a variety of chemokines, but CXCR4 is an exception, and is specific for the chemokine CXCL12. Together, they normally play an essential role in the development of blood cells, but they are also important in disease. For instance, communication through CXCR4 may promote the many pathological changes in cancer cells, including formation of metastases and abnormal growth of blood vessels. CXCR4 also plays a central role in infection by HIV, since it is the co-receptor that guides the virus into cells.

CXCR4 IN ACTION

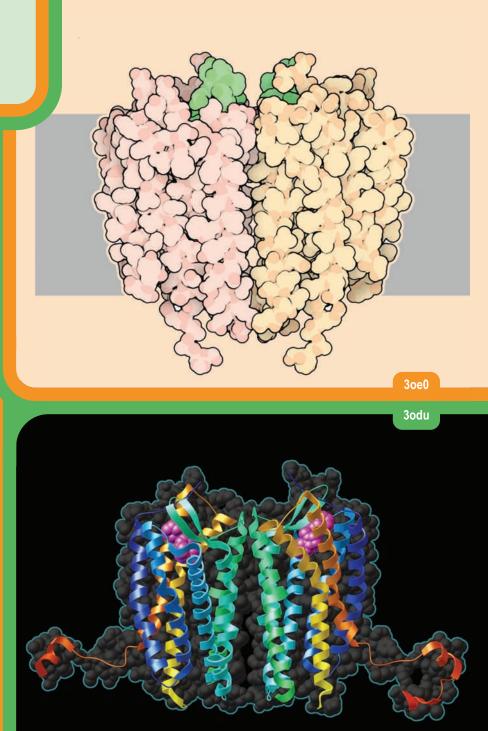
The structure of CXCR4 revealed the signature core of GPCRs: a bundle of seven alpha helices that criss-cross through the cell membrane. These are connected by a series of loops that are exposed on the two sides of the membrane and perform much of the work of recognizing the chemokine and passing the signal inside. The binding site is a cup-shaped depression on the outer surface. Crystal structures were obtained with a large cyclic peptide bound in the active site (shown at the top here from PDB entry **30e0**), suggesting how the chemokine might bind, and also with a small inhibitor bound (shown below from PDB entry **30du**), providing a place to start for design of anti-HIV drugs.

SOLVING THE STRUCTURE

Membrane proteins are always challenging targets for crystallography, because they need to be separated from their comfortable membrane environment. CXCR4 is no exception, so in order to solve the structure, the PSI team engineered a more cooperative form of the receptor. They clipped one of the intracellular loops of the receptor and inserted an entire molecule of lysozyme. The two-part protein folds correctly, is still active as a receptor, and with some coaxing, forms high-quality crystals for structure solution.

Wu, B. et al. Structures of the CXCR4 chemokine GPCR with small-molecule and cyclic peptide antagonists. *Science* 330, 1066-1071 (2010). PDB ID 30e0

Alkhatib, G. The biology of CCR5 and CXCR4. *Curr. Op. HIV AIDS* 4, 96-103 (2009). Wu, B. et al. Structures of the CXCR4 chemoking CPCR with small-molecule and cyclic peptide antagonists. *Science* 330, 1066-1071 (2010) PDB ID 30du



The PSI:Biology-Material Repository (PSI-MR) stores and distributes PSI-created DNA clones and vectors to the greater scientific community. For more info, visit

psimr.asu.edu

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
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11 Veterans Day	12	13	14	15	16	17
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TrkH Potassium Ion Transporter

doi:10.3942/psi_sbkb/fm_2011_04

Cells are filled with a soup of metal ions. These ions are used in many different roles. Highly charged ions like iron and magnesium are often used as chemical tools by metalloenzymes, which capture individual metal ions and use them to recognize their substrates or catalyze their reactions. Sodium and potassium ions, on the other hand, are often used en masse for jobs like signaling or tuning the internal pressure of a cell. These jobs rely more on the overall concentration of the ions rather than a specific location of each one.

ION TRAFFIC

To control the concentration of ions, cells have evolved a complex collection of transporters and channels that control a constant traffic of ions across cell membranes. Some of these proteins, such as bacterial porins, are simple holes through the membrane, allowing anything smaller than a given size to pass. Others, however, are highly specific, selecting and transporting only one particular type of ion. Researchers at NYCOMPS have solved the structure of a new transporter for potassium ions, and discovered the atomic basis for its selectivity.

SELECTING POTASSIUM

Potassium channels contain a "selectivity filter" with a very specific arrangement of oxygen atoms, as shown in the Jmol image below. These oxygen atoms perfectly mimic the shell of waters that normally surround the ion when it is free in solution. The water shells are quite different between sodium and potassium ions, so by making the arrangement in the pore similar to the potassium hydration shell, the protein can favor the desolvation and passage of potassium rather than sodium. By taking advantage of this difference, some potassium channels allow only a single sodium ion to pass for every 10,000 potassium ions that flow through.

STRUCTURES FOR SPECIFICITY

The TrkH structure, available in PDB entry 3pjz, adds several new wrinkles to the story of potassium transport. The previously studied channels are composed of four identical subunits that together form a symmetrical pore, with each subunit providing one fourth of the selectivity filter. The channel in TrkH, on the other hand, is formed by a single protein chain. The sequence of this filter is also highly constrained and the slightest mutation will abolish the selectivity. This chain forms all of the familiar functional structures needed for potassium passage, including a cage of oxygen atoms to act as the selectivity filter, and a set of pore helices angled to point their negative ends towards the potassium site. Surprisingly, the sequence of amino acids has several changes from the symmetrical channel proteins, showing that there are alternative ways to achieve specificity for potassium. However, although TrkH is known to select potassium ions over smaller ones like sodium and lithium, researchers are still testing whether it is as selective as the symmetrical potassium channels.

3pjz

TRANSPORT OF POTASSIUM

In cells, TrkH forms a dimer, with two side-by-side pores, and works along with several other proteins to transport potassium across the cell membrane. The structure of TrkH suggests its role as a potassiumspecific channel, although biochemical studies have shown that the rate of passage is significantly slower than in other potassium channels. This may be due to a small loop that partially blocks the pore. It is still a mystery, however, whether TrkH is the engine that performs potassium transport, or simply works as part of a larger machine, acting as the filter that sorts potassium ions from other ions.

Cao, Y. et al. Crystal structure of a potassium ion transporter, TrkH. Nature 471, 336-340 (2011). doi:10.1038/nature09731; PDB ID 3pjz

Doyle, D. A. et al. The structure of the potassium channel: molecular basis of K+ conduction and specificity. Science 280, 69-77 (1998).

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Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
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PSI Featured Systems

The Perils of Protein Secretion	Pseudouridine Synthase TruA	Hemolysin BL	Exploring the Secre- tome of Gut Bacteria	Antibiotics and Ribosome Function	Mre11 Nuclease
		March			June
January Bacterial Armor	February Superbugs and	Zinc Transporter ZntB	April Rb Tumor Suppressor	May CXCR4	TrkH Potassium Ion
	Antibiotic Resistance		and Cancer		Transporter
Sim	and and the	CHARTER S		and the	