March 2000: DNA Polymerase

The Secret of Life

DNA polymerase plays the central role in the processes of life. It carries the weighty responsibility of duplicating our genetic information. Each time a cell divides, DNA polymerase duplicates all of its DNA, and the cell passes one copy to each daughter cell. In this way, genetic information is passed from generation to generation. Our inheritance of DNA creates a living link from each our own cells back through trillions of generations to the first primordial cells on Earth. The information contained in our DNA, modified and improved over millennia, is our most precious possession, given to us by our parents at birth and passed to our children.

Amazing Accuracy

DNA polymerase is the most accurate enzyme. It creates an exact copy of your DNA each time, making less than one mistake in a billion bases. This is far better than information in our own world: imagine reading a thousand novels, and finding only one mistake. The excellent match of cytosine to guanine and adenine to thymine, the language of DNA, provides much of the specificity needed for this high accuracy. But DNA polymerase adds an extra step. After it copies each base, it proofreads it and cuts it out if the base is wrong.

Prisoners and Pedigrees

Your DNA is unique to you, more unique than any fingerprint. Your DNA is a mixture of your mother's and your father's DNA, plus perhaps a few mutational changes. This uniqueness has been used to great advantage in criminal forensics. If a drop of blood is left at a crime scene, the DNA may be analyzed and compared with the DNA of a suspected criminal. If they match, the criminal has been caught in the act.

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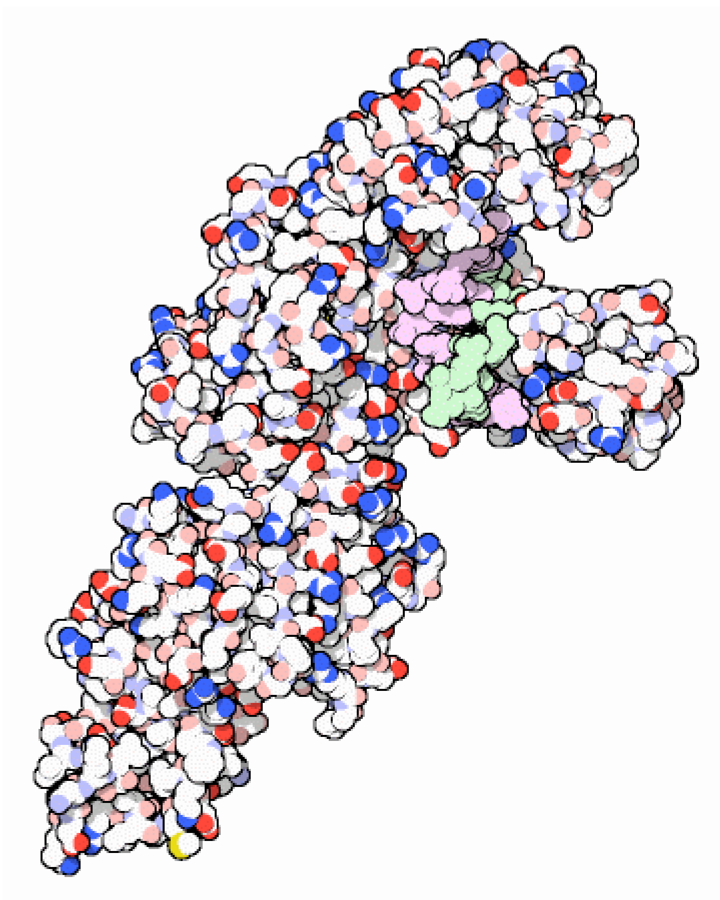
Of course, there is very little DNA in a dried drop of blood. This is where DNA polymerase enters the world of forensics. A small sample of DNA is multiplied using PCR (the polymerase chain reaction), creating a large sample that may be easily analyzed. The tiny sample is placed in a test tube, and DNA polymerase is added to make a copy. Then the sample is heated up momentarily, and the two strands of DNA separate. Then DNA polymerase builds a new double helix from each strand. These two copies are then heated, and duplicated, yielding four copies. After many times, a large quantity of identical DNA strands are produced. Our own DNA polymerases, and those from most organisms, would be destroyed by the heating step in this process. But today, DNA polymerase from *Thermus aquaticus*, a bacterium that lives in hot springs, is used. This polymerase, shown in the picture here, is perfectly happy at 70 degrees centigrade, and may be used throughout all of the PCR heating and cooling steps. This enzyme may be found in the PDB in the file 1tau.



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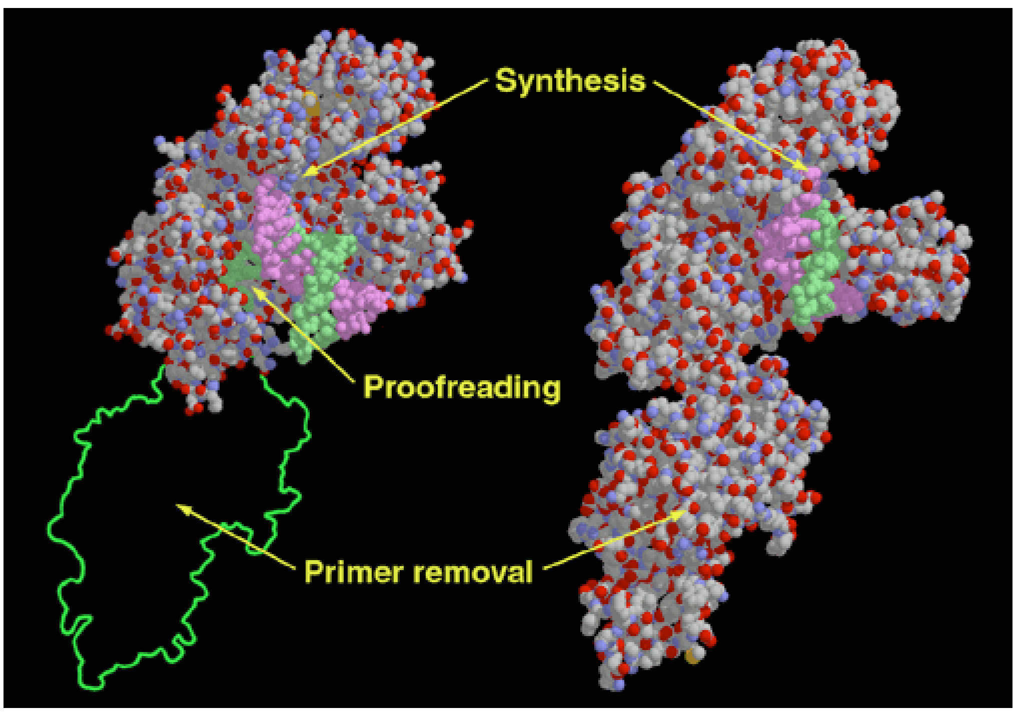
Exploring the Structure

These simple DNA polymerases are shaped roughly like a hand. Both are from bacteria: on the left is the enzyme from *Escherichia coli*, PDB entry 1kln, and on the right is the enzyme from *Thermus aquaticus*, PDB entry 1tau. A cleaved version of the *E. coli* enzyme was studied: the missing part, which you will not find in the PDB file, is shown with a green outline. The space between the "fingers" and the "thumb" is just the right size for a DNA helix. But surprisingly, DNA actually fits into the palm when the enzyme is at work. In these pictures, the template strand is colored purple and the new strand is colored green. The enzyme contains three separate active sites. The polymerase site, near the top in these pictures, synthesizes the new strand by adding nucleotides. The 3'-5' exonuclease site, near the center in the *E. coli* polymerase, proofreads the new additions. The polymerase from *Thermus aquaticus* does not have this proofreading ability--perhaps the heat in which it lives performs the same function. At the bottom is the 5' exonuclease site that later removes the small RNA fragments that are used to prime DNA replication.



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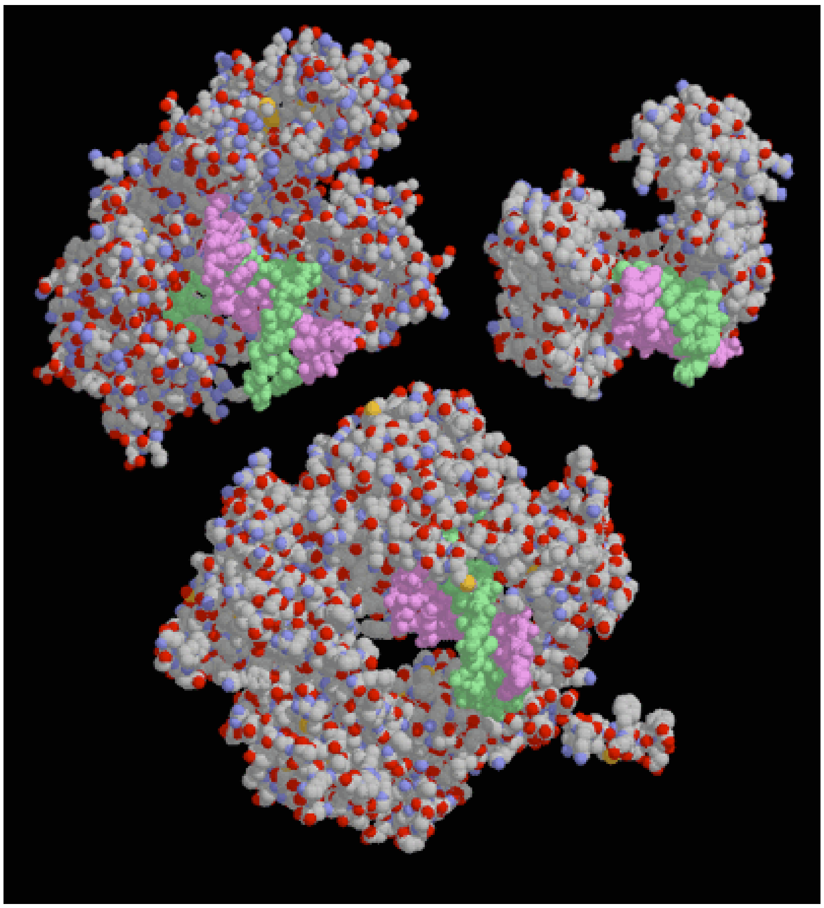
Distant Relatives

All living organisms have DNA polymerases. Some, like the ones pictured here, are quite simple: one enzyme does it all. The ones in our own cells are more complex, composed of separate proteins that unwind the helix, build an RNA primer, and build the new strand. Some even have a ring-shaped protein that clamps the polymerase to the DNA strand. A single cell often has several different polymerases: complex ones that do the major DNA replication when the cell divides, and simpler ones that help in day-to-day repair and maintenance of the DNA.



Three simple polymerases are pictured above, each with a tiny piece of DNA bound. In each picture, the template DNA strand is colored purple and the newly built strand is colored green. At upper left is DNA polymerase I from *Escherichia coli*, with PDB accession code 1kln. At upper right is human DNA polymerase, from the PDB file 1zqa. At bottom is a viral DNA polymerase, from the PDB file 1clq. The are quite different in size and shape, but notice how all wrap around the DNA, and enclosing the end of the DNA in a pocket in which the synthetic reaction is performed.