proteinspotlight
> ONE MONTH, ONE PROTEIN <

Issue 24, July 2002
www.proteinspotlight.org

The tiptoe of an airbus

Vivienne Baillie Gerritsen

In the 1900s, the Swiss physicist Auguste Piccard invented the bathyscaph, a submersible vessel for deep-sea observation. Long before though, spiders had already thought up a way of carrying out deep-pond observations using the same kind of strategy. A species of spider that lives in freshwater ponds throughout Europe weaves its own bathyscaph with silk. Bubbles of air keep the contraption afloat and a silk thread tethers it to a plant. Spiders use their silk for a number of purposes: besides catching their dinner by way of a woven web, some male spiders deposit sperm onto it and then offer the parcel to a female's genital opening. Silk is also used to wrap eggs in a silken cocoon or to hold offspring by means of a silk lifeline.

Human societies have made great use of spider silk in the past. The Ancient Greeks used cobwebs to staunch bleeding wounds. The French naturalist René-Antoine Ferchault de Réaumur was asked to find an application for spider silk in the early 1800s, and all his efforts went into ladies' accessories such as stockings and gloves…only he did not have enough spiders for the job. To this day, Australian aborigines use the silk of a giant spider for fishing lines. And right up to World War II, spider silk was used for crosshairs in optical devices such as microscopes, guns and bomb-guiding systems since it is 40 times finer than human hair. Currently, although crosshairs are now etched or made with metal filaments, some military facilities still keep a domesticated black widow spider as a silk provision for old instruments.

A specific type of spider silk – dragline silk – has been very popular in the last decade. Dragline silk is the thread spiders use to make the scaffolding of their webs and the thread from which they hang. And it is one of the toughest materials known to date. Surprising when you know that the flick of a feather duster is sufficient to whip a web away from the ceiling. In fact, a cable not much thicker than a garden hose could support a fully loaded Airbus without snapping. And besides its toughness, spider silk is made from protein and water at a relatively low temperature, which is far more environmentally friendly than the fabrication of Kevlar, for instance, which demands that concentrated sulfuric acid be heated to boiling point and whose by-products are dangerous and expensive to dispose of. Dragline silk is both a strong and an extensible fibre. In other words: tough. A spider fibre can not only stretch by 40% of its length but it can also absorb a hundred times as much energy as steel without breaking. It is the extensibility factor of spider silk that makes it so special. Many man-made materials are strong but lack this specificity which is why a lot of research has been carried out to understand spider silks on the molecular level.

Nephila clavipes

Courtesy of Frank Starmer

It is dragline silk from the golden orb weaver (*Nephila clavipes*), which – until now – has met with the most enthusiasm. Spider silk is made up of different regions, or modules. These modules consist of crystalline beta sheets and amorphous regions, which are thought to be simple stretches of 16 to 20 amino acids. The crystals impart robustness to the proteins while the amorphous regions bestow extensibility. Different silks have different concentrations of crystals and thus different mechanical properties. The concentration of beta sheets in dragline silk is about 25%.

Specialised columnar epithelial cells synthesize the silk proteins and secrete them into the lumen of a storage gland, where they are stored as liquid crystal. The viscous brew is then pushed through a duct which leads to the spinnerets, i.e. the organs from which the mature silk fibre is drawn. How is the water squeezed out? The amorphous regions may curl up in the storage glands in such a way that they retain water molecules. In the duct, the proteins are straightened and the water molecules retained by microvilli which line the interior of the duct. The result is a silk fibre made of concentric layers of nanofibrils. Some of these fibrils follow the axis of the fibre's core, whilst others coil around the fibre like a spiral staircase. This quaternary structure makes the fibre tougher. The angled nanofibrils have then to be stretched into a straighter conformation before any breaking of the silk fibre can occur.

The idea behind research is to have a deep understanding of each module in order to produce a custom-made silk fibre. There is still a major drawback though: supercontraction. Indeed, spider fibre shrinks to as little as 55% of its original length when wet. This is an ideal property for silk fibre when a slack cobweb is tightened with the morning dew. However it is a problem for the creation of biomaterials. Just imagine a bullet proof vest under the rain. What causes the fibre to tighten is probably an 11 amino-acid stretch in the amorphous region. When water hits it, it swells and pushes the crystalline structures out of line, causing the fibre to contract.

Fossil evidence from rocks near New York shows that spiders were spinning silk as long as 380 million years ago. But humans still have quite a way to go before they start spinning silk to make artificial tendons or to tether satellites in space.

Cross-references to Swiss-Prot

Dragline silk fibroin 1, *Nephila clavipes* (Orb spider) : P19837
Dragline silk fibroin 2, *Nephila clavipes* (Orb spider) : P46804

References

1. Lewis R.
   Unravelling the weave of spider silk
   Bioscience 46:336-338(1996)

2. Gosline J.M., Guerette P.A., Ortlepp C.S., Savage K.N.
   The mechanical design of spider silks: from fibroin sequence to mechanical function
   J. Exp. Biol. 202:3295-3303(1999)
   PMID: 10562512

3. Hinman M.B., Jones J.A., Lewis R.V.
   Synthetic spider silk: a modular fiber
   Trends Biotechnol. 18:374-379(2000)
   PMID: 10942961

4. Fox D.
   The spinners
   The New Scientist magazine, vol. 162, April 1999, p.38

5. Jones N.
   Why spiders shouldn't jump out of planes
   The New Scientist magazine, vol. 168, October 2000, p.22

Protein Spotlight (ISSN 1424-4721), http://www.proteinspotlight.org, is published by the Swiss-Prot group at the Swiss Institute of Bioinformatics (SIB). Authorization to photocopy or reproduce this article for internal or personal use is granted by the SIB provided its content is not modified. Please enquire at spotlight@isb-sib.ch for redistribution or commercial usage.