

DNA-inspired 'supercoiling' fibers could make powerful artificial muscles for robots

April 29 2021, by Geoff Spinks



Credit: AI-generated image ([disclaimer](#))

The double helix of DNA is one of the most iconic symbols in science. By imitating the structure of this complex genetic molecule [we have found a way](#) to make artificial muscle fibers far more powerful than those found in nature, with potential applications in many kinds of miniature machinery such as prosthetic hands and dextrous robotic

devices.

The power of the helix

DNA is not the only helix in nature. Flip through any biology textbook and you'll see helices everywhere from the [alpha-helix](#) shapes of individual proteins to the "coiled coil" helices of fibrous protein assemblies like [keratin](#) in hair.

Some bacteria, such as [spirochetes](#), adopt helical shapes. Even the [cell walls of plants](#) can contain helically arranged cellulose fibers.

Muscle tissue too is composed of helically wrapped proteins that form thin filaments. And there are many other examples, which poses the question of whether the helix endows a particular evolutionary advantage.

Many of these naturally occurring helical structures are involved in making things move, like the [opening of seed pods](#) and the twisting of trunks, tongues and tentacles. These systems share a common structure: helically oriented fibers embedded in a squishy matrix which allows complex mechanical actions like bending, twisting, lengthening and shortening, or coiling.

This versatility in achieving complex shapeshifting may hint at the reason for the prevalence of helices in nature.

Fibers in a twist

Ten years ago my work on [artificial muscles](#) brought me to think a lot about helices. My colleagues and I discovered a simple way to make powerful [rotating artificial muscle fibers](#) by simply twisting synthetic

yarns.

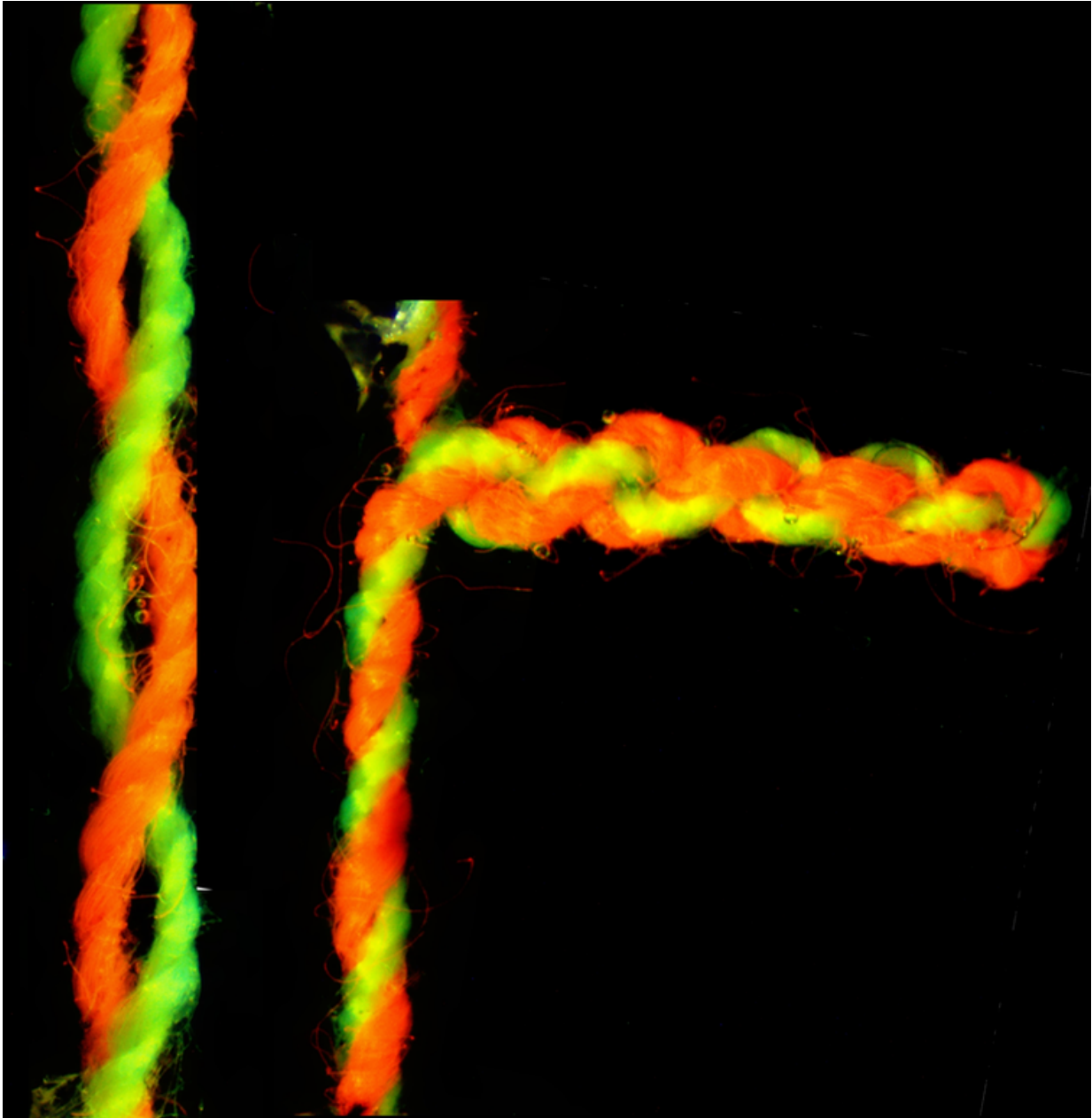
These yarn fibers could rotate by untwisting when we expanded the volume of the yarn by heating it, making it absorb small molecules, or by charging it like a battery. Shrinking the fiber caused the fibers to re-twist.

We [demonstrated](#) that these fibers could spin a rotor at speeds of up to 11,500 revolutions per minute. While the fibers were small, we showed they could produce about as much torque per kilogram as large electric motors.

The key was to make sure the helically arranged filaments in the yarn were quite stiff. To accommodate an overall volume increase in the yarn, the individual filaments must either stretch in length or untwist. When the filaments are too stiff to stretch, the result is untwisting of the yarn.

Learning from DNA

More recently, I realized DNA molecules behave like our untwisting yarns. Biologists studying [single DNA molecules](#) showed that double-stranded DNA unwinds when treated with [small molecules](#) that insert themselves inside the double helix structure.



An untwisted fibre (left) and the supercoiled version (right). Credit: Geoff Spinks, Author provided

The backbone of DNA is a stiff chain of molecules called sugar phosphates, so when the small inserted molecules push the two strands of

DNA apart the double helix unwinds. Experiments also [showed](#) that, if the ends of the DNA are tethered to stop them rotating, the untwisting leads to "supercoiling": the DNA molecule forms a loop that wraps around itself.

In fact, special proteins induce [coordinated supercoiling](#) in our cells to pack DNA molecules into the tiny nucleus.

We also see supercoiling in [everyday life](#), for example when a garden hose becomes tangled. Twisting any long fiber can produce supercoiling, which is known as "snarling" in textiles processing or "hockling" when cables become snagged.

Supercoiling for stronger 'artificial muscles'

Our latest results show [DNA-like supercoiling](#) can be induced by swelling pre-twisted textile fibers. We made composite fibers with two polyester sewing threads, each coated in a hydrogel that swells up when it gets wet and then the pair twisted together.

Swelling the hydrogel by immersing it in water caused the composite fiber to untwist. But if the fiber ends were clamped to stop untwisting, the fiber began to supercoil instead.

As a result, the fiber shrank by up to 90% of its original length. In the process of shrinking, it did mechanical work equivalent to putting out 1 joule of energy per gram of dry fiber.

For comparison, the muscle fibers of mammals like us only shrink by about 20% of their original length and produce a work output of 0.03 joules per gram. This means that the same lifting effort can be achieved in a supercoiling fiber that is 30 times smaller in diameter compared with our own muscles.

Why artificial muscles?

Artificial muscle materials are especially useful in applications where space is limited. For example, the latest motor-driven [prosthetic hands](#) are impressive, but they do not currently match the dexterity of a human hand. More actuators are needed to replicate the full range of motion, grip types and strength of a healthy human.

Electric motors become much less powerful as their size is reduced, which makes them less useful in prosthetics and other miniature machines. However, artificial muscles maintain a high work and power output at small scales.

To demonstrate their potential applications, we used our supercoiling muscle fibers to open and close miniature tweezers. Such tools may be part of the next generation of non-invasive surgery or robotic surgical systems.

Many new types of artificial muscles have been introduced by researchers over the past decade. This is a very active area of research driven by the need for miniaturized mechanical devices. While great progress has been made, we still do not have an artificial muscle that completely matches the performance of natural [muscle](#): large contractions, high speed, efficiency, long operating life, silent operation and safe for use in contact with humans.

The new supercoiling muscles take us one step closer to this goal by introducing a new mechanism for generating very large contractions. Currently our fibers operate slowly, but we see avenues for greatly increasing the speed of response and this will be the focus for ongoing research.

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