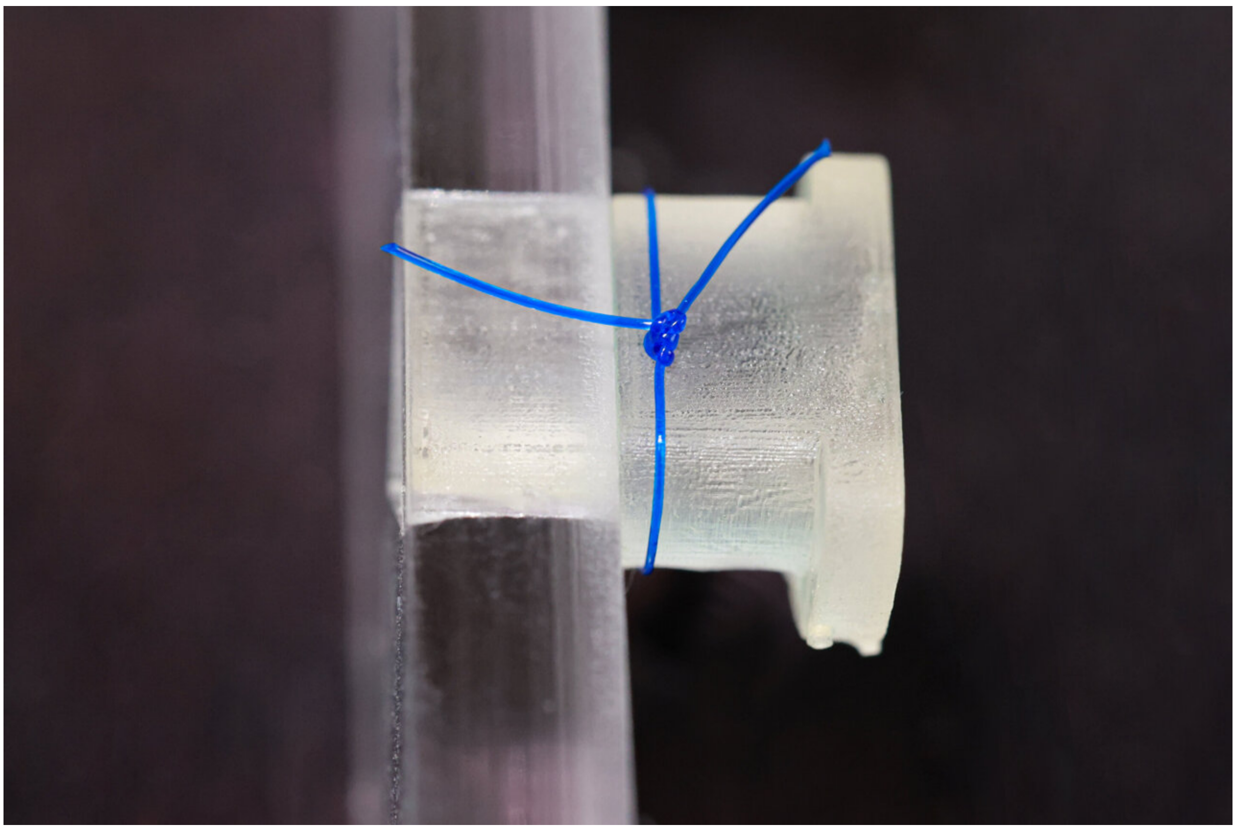
Study reveals mechanics of the ideal surgical knot

June 9 2023



Surgical knot tied on a rigid support. Credit: Alain Herzog / EPFL

Think about the last time you tied your shoe: maybe you tied it tightly, or tied multiple knots to ensure the laces wouldn't come undone. You likely relied on intuition to tell you how much tension to apply to keep the laces from untying, without pulling hard enough to break them.

Perhaps surprisingly, surgeons also take an intuitive approach to knotting sutures. While simple square and granny sliding knots are often used in surgery, it takes years to master them so that they stay in place without loosening or breaking. Much mathematical research has been done on knot topology and geometry, but little is known about knot mechanics in the context of physical variables, like the material properties of knotted filaments.

"It's astonishing to think how much we rely on knots, when we don't really understand how they work," says Pedro Reis, head of the Flexible Structures Lab in the School of Engineering (Institute of Mechanical Engineering). Reis and Ph.D. student Paul Johanns teamed up with Lausanne-based plastic surgeon Samia Guerid to lead a first physics-based study published in *Science Advances* on the mechanics of surgical knots, and exactly what properties influence their strength.

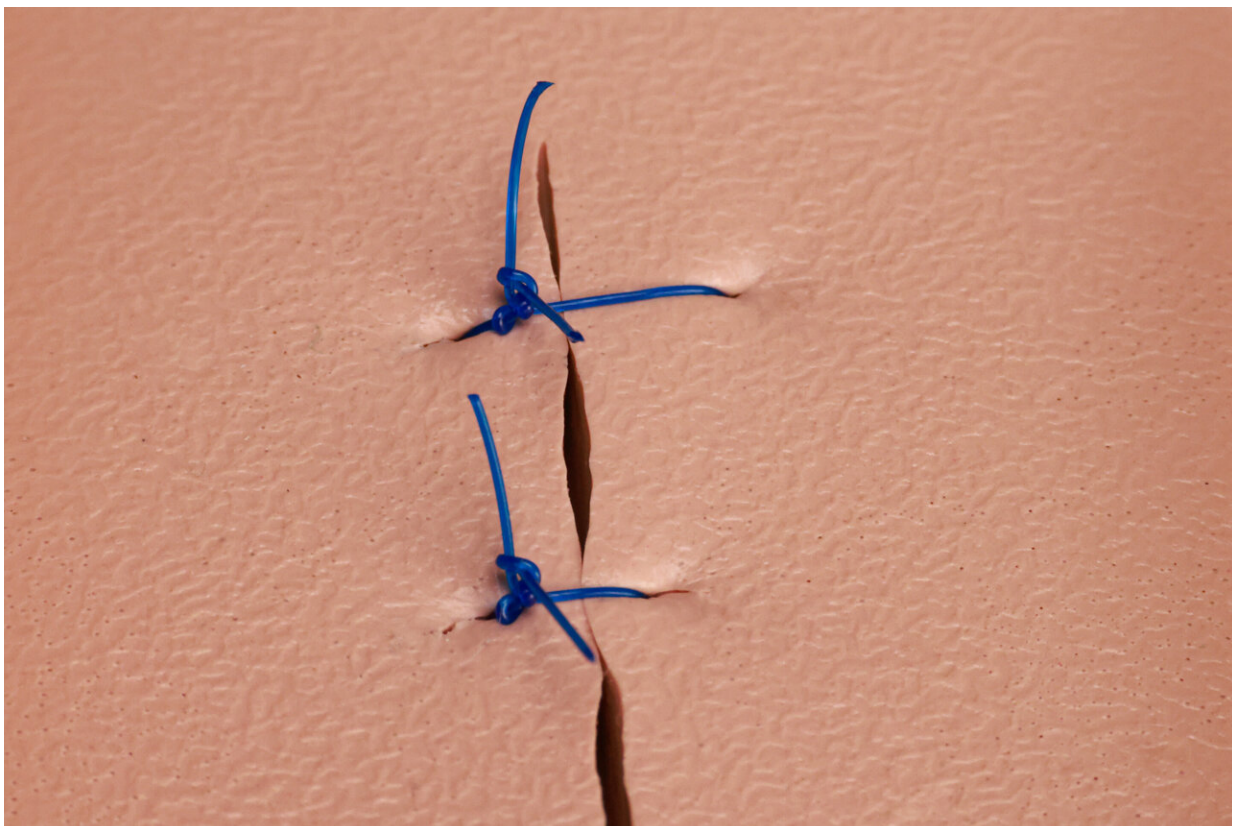
"Understanding surgical knot mechanics can raise awareness among experienced surgeons, be incorporated into training programs, and advance robotic surgery by enabling more effective knot-tying capabilities," says Guerid. "Such knowledge could also influence the development of suture materials that enhance slippage resistance in sliding knots."

The power of plasticity

Reis, an avid climber, has a personal interest in secure knots and has conducted several previous studies on knot mechanics. He explains that many knots can be described as free-ended structures that provide a holding force, with their functionality dictated by the variables of topology, geometry, elasticity, contact, and friction. But for the study of surgical knots, Reis and his colleagues considered a key sixth factor:

polymer plasticity of the suturing filament.

The strength of sutures made from polypropylene filaments used in surgery depends on the tension applied during the tying of the knot (pretension). This pretension permanently deforms, or stretches the filament, creating a holding force. Too little pretension causes the knot to come undone; too much snaps the filament.



Surgical knot tied on a suturing pad. Credit: Alain Herzog / EPFL

The team analyzed 50-100 knots tied by Guerid, and found that the surgeon was able, thanks to her years of experience, to intuitively target the pretension "sweet spot." Using precision experiments, X-ray micro-computed tomography, and computer simulations, the scientists defined a threshold between "loose" and "tight" knots, and uncovered relationships between knot strength and pretension, friction, and number of throws.

"Surprisingly, despite the complex interplay between all six factors, we observed a simple, robust emergent behavior vis-à-vis knot strength. But we still don't have a predictive model to fully explain the relationship between knot pretension and strength, which seems to be consistent, even outside surgical knots. We're already looking into this question."

A training tool for surgeons…and robots

The team's findings could be a valuable tool for training surgeons, as they could allow the parameters of a secure knot to be translated into practical guidelines. While experience would remain important, the idea is that safe knot-tying could be taught using predictive models, rather than intuition gained only through years of practice.

"Our data gives us a recipe for determining the ideal pretension and number of throws, for example, depending on the type of filament used," Reis says

"The lack of physics-based analysis has been a limitation," Guerid adds. "Quantifiable data on knot mechanics could be integrated into training programs to assess the tensile strength of each knot, ensuring trainees acquire necessary skills for successful surgeries. The data could also facilitate development of robotic surgery via the programming of robotic systems."

More information: Paul Johanns et al, The strength of surgical knots involves a critical interplay between friction and elastoplasticity, *Science*

Advances (2023). DOI: 10.1126/sciadv.adg8861

Provided by Ecole Polytechnique Federale de Lausanne