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Pedro M. Reis, Ji-Sung Park, and Javier Sabater
"The mechanics of physical knots: from shoelaces to surgical sutures"

Pedro M. Reis is a Professor of Mechanical Engineering at EPFL, Switzerland. He holds a B.Sc. and Ph.D. in Physics from the University of Manchester, and a Certificate of Advanced Studies in Mathematics from the University of Cambridge. After postdoctoral positions at the City College of New York and CNRS/ESPCI Paris, he joined the faculty at MIT in 2007 and moved to EPFL in 2017. At EPFL, he heads the fleXLab (https://flexlab.epfl.ch/). He was named to Popular Science's "Brilliant 10" list (2013) and has received the NSF CAREER Award (2014), the ASME Thomas J.R. Hughes Young Investigator Award (2016), and the APS GSOFT Early Career Award (2016). He is a Fellow of the American Physical Society and served as President of the Society of Engineering Science (2021). The talk will be co-presented by Ji-Sung Park (B.Sc. and integrated M.Sc./Ph.D. in Mechanical Engineering, Seoul National University), and Javier Sabater (B.Sc. and M.Sc. in Industrial Technologies Engineering, Universitat Jaume I; M.Sc. in Mechanical Engineering, INSA Lyon), who are, respectively, a postdoctoral researcher and a Ph.D. student at the fleXLab.

Although most of us tie our shoelaces "wrongly," knots in ropes and filaments have served as functional structures for millennia, from sailing and climbing to sewing and surgery. Yet knowledge of physical knots remains largely empirical, and mechanics-based predictive models are lacking. Tight knots exhibit highly nonlinear, coupled behavior due to their intricate 3D geometry, large deformations, self-contact, friction, and polymer elasto-plasticity, making their modeling a challenging problem in mechanics. In this talk, we present recent work from our group combining precision experiments, FEM simulations, and analysis. We focus on surgical knots, which carry a particularly high risk of failure in clinical settings, including massive bleeding or unraveling of high-tension closures. Our results reveal a robust superlinear relationship among knot strength, applied pre-tension, and the number of throws, rationalized by a reduced-order model based on the capstan problem and Euler's elastica. We also examine overhand, figure-8, clove-hitch, and bowline knots, as well as knots in fluid-conveying biological tubes. Our findings have implications for clinical settings, surgical training, robotic-assisted surgery, and more mundane activities such as shoelace tying, sailing, and climbing.