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Cell Entry of One-Dimensional Nanomaterials

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Materials with high aspect ratio, such as carbon nanotubes, have been shown to cause length-dependent toxicity in certain cells because their long length prevents complete ingestion, which frustrates the cell. Biophysical models have been proposed to explain how spheres and elliptical nanostructures enter cells but one-dimensional nanomaterials have not been examined. Here we show experimentally and theoretically that cylindrical one-dimensional nanomaterials such as carbon nanotubes enter cells through the tip first. For nanotubes with end caps or carbon shells at their tips, uptake involves tip recognition through receptor binding, rotation driven by asymmetric elastic strain at the tube-bilayer interface, and then near-vertical entry. The precise angle of entry is governed by the relative time scales for tube rotation and receptor diffusion. Nanotubes without caps or shells on their tips show a different mode of membrane interaction, posing an interesting question whether modifying the tube tips may help avoid frustrated uptake.

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