# Finite element analysis of polymeric microneedle insertion into skin

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**Rationale and objectives:** Microneedles are tiny needles (smaller than 1 millimeter) that can deliver drugs and vaccines through the skin painlessly. While polymer-based microneedles are attractive because they're cheap to manufacture and can dissolve to release medicine, they face a major problem: they're not as strong as metal needles and can break or bend when pressed into skin. Previous computer models treated microneedles like rigid metal objects, which doesn't capture how plastic microneedles actually deform. This study aimed to create a more realistic computer simulation to understand how polymer microneedles behave during skin insertion, especially under real-world conditions like when the needle patch is applied at an angle or on curved body parts.

**Summary:** The researchers developed a detailed computer model to simulate polystyrene microneedles being inserted into a two-layer artificial skin model. They tested various scenarios including what happens when needles are inserted at different angles, how skin curvature affects insertion, and how different needle designs perform (varying shapes, sizes, and spacing between needles). They also compared four different polymer materials commonly used for microneedles. The model treated the microneedles as flexible materials that could bend and deform, rather than rigid objects, allowing the researchers to see where stresses build up and predict potential failure points.

**Outcome**: The study revealed several critical findings for microneedle design. Even a tiny 5-degree misalignment during application can cause the needles to exceed their breaking point, highlighting the need for precise applicators. Curved skin surfaces (like on arms) create uneven forces that particularly stress the outer needles in an array. The needle's tip sharpness dramatically affects the force needed for insertion - sharper tips require less force. Importantly, not all polymer materials are strong enough; while polystyrene, polycarbonate, and polylactic acid successfully penetrated the skin model, hyaluronic acid failed. The research provides specific design recommendations, such as maintaining needle spacing of at least 1 millimeter and using an aspect ratio of 3:1 for optimal strength without sacrificing penetration ability.

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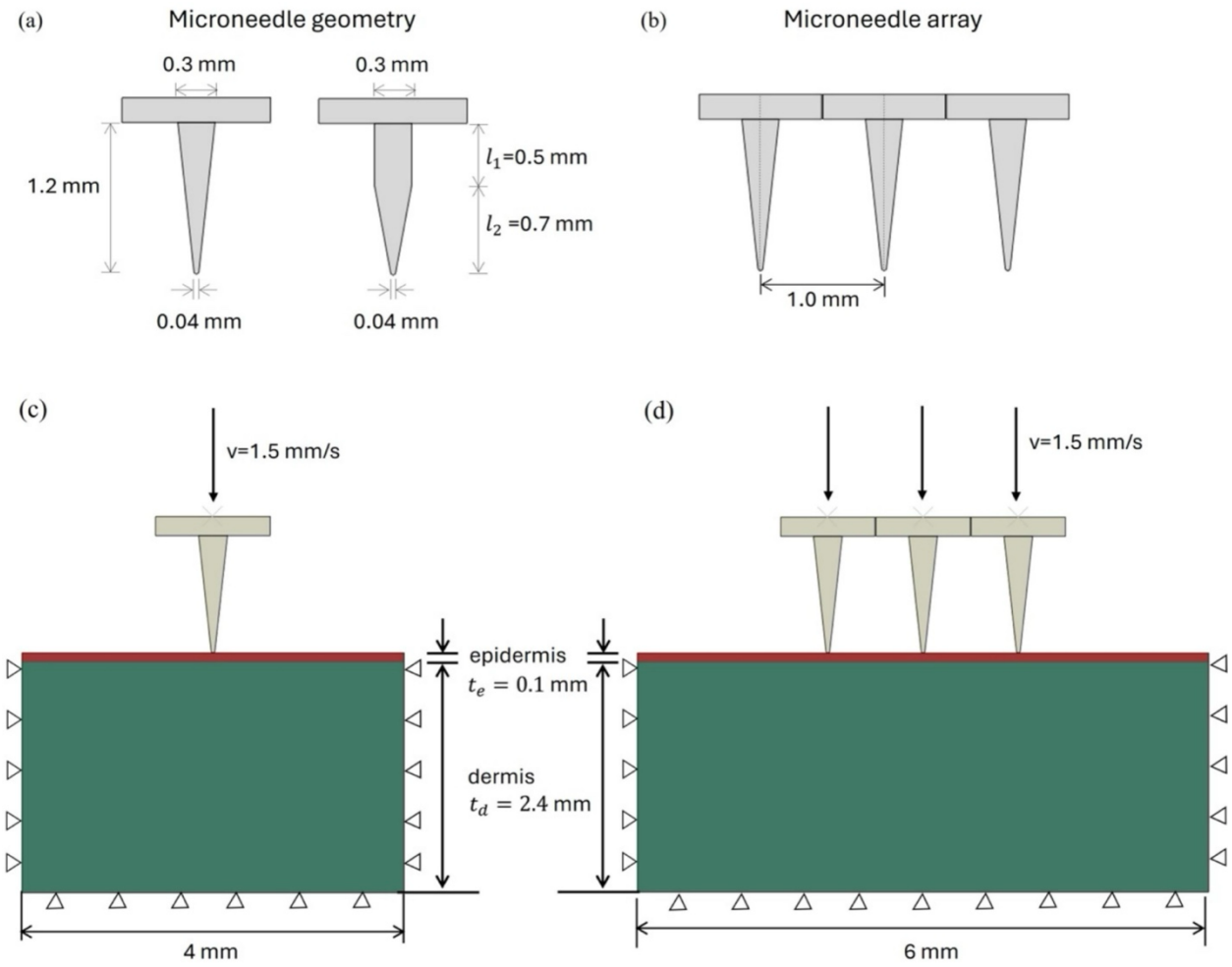
**Related SDGs goal**: 3. Good health and well-being.




**Graphical summary:** Microneedle geometry, model definition and boundary conditions. **(a)** A single microneedle; cone and tapered cone shape, and **(b)** a 3-microneedle array. **(c)** a single microneedle insertion model at initial time, and **(d)** a 3-microneedle array insertion model at initial stage.

**Related publication**:

Yolai N, Shu W, O'cearbhaill ED, **Modchang C**, and Annaidh AN. Finite element analysis of polymeric microneedle insertion into skin. *Materials & Design*. https://doi.org/10.1016/j.matdes.2025.114936