Wearable Printed Sensors for Non-Invasive Penile Tumescence Monitoring

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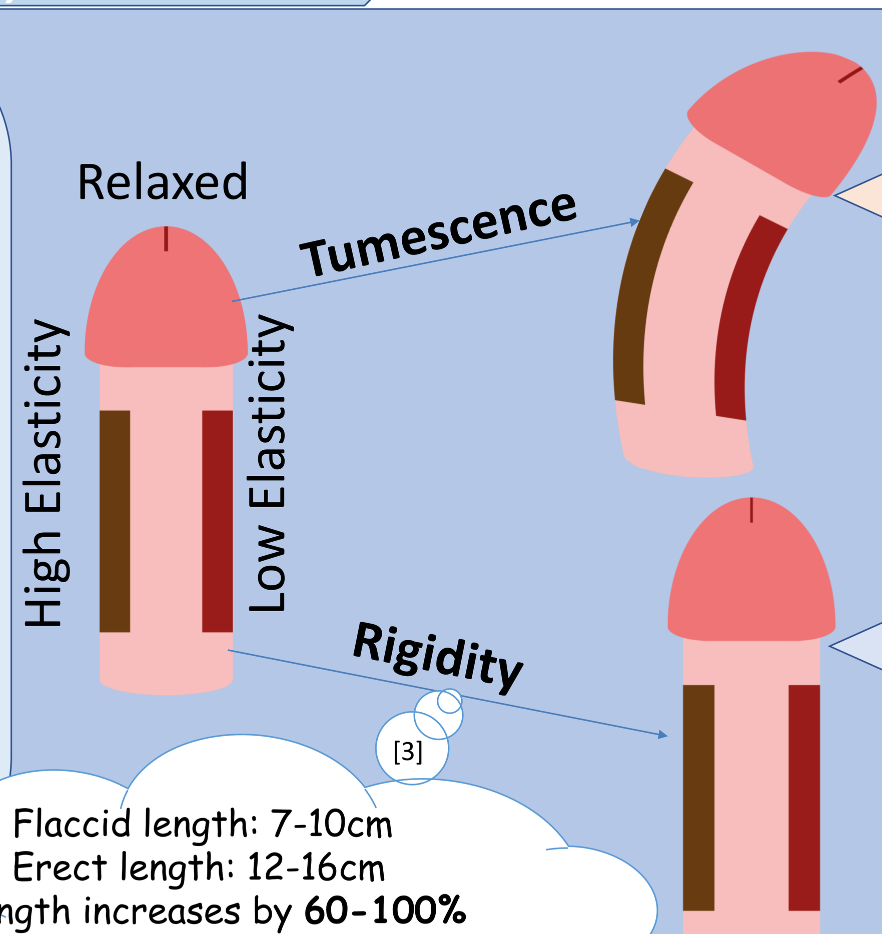
Background

Erectile Dysfunction (ED) affects approximately 50% of men over the age of 50, posing significant challenges to quality of life and psychological well-being [1]. Traditional assessment methods, such as subjective questionnaires and devices like the RigiScan®, often fall short due to discomfort, complexity, and limited accuracy [2]. To address these limitations, we have developed a wearable, fully printed sensor patch designed for non-invasive, continuous monitoring of penile tumescence and rigidity. This innovative patch utilizes flexible, stretchable strain gauges printed on a biocompatible elastomeric substrate, enabling high-resolution tracking of axial rigidity changes during nocturnal penile tumescence (NPT) events. Our technology offers a user-friendly solution that overcomes the drawbacks of existing methods, providing reliable data for clinicians and enhancing patient comfort. By integrating advanced materials and printing techniques, this sensor patch represents a significant step forward in the objective assessment and management of ED.



When tumescence takes place **without** the penis getting hard, the sensor strip with the lowest elasticity will exert a great resistance and make the penis bend. This results in a big increase of the left sensor. The right sensor will barely increase.

When the penis erects **and** gets hard, both the sensor strips will start to deform, resulting in resistance changes. Rigidity is being measured by looking at the ratio of both the sensor strips.

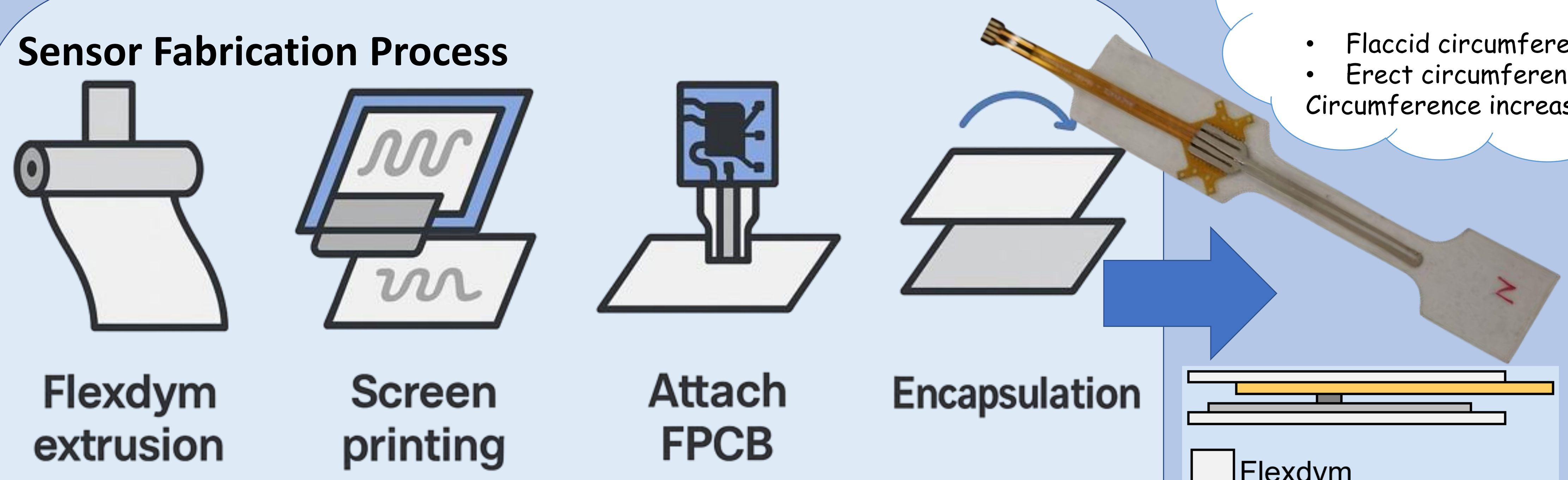
- Flaccid length: 7-10cm
- Erect length: 12-16cm

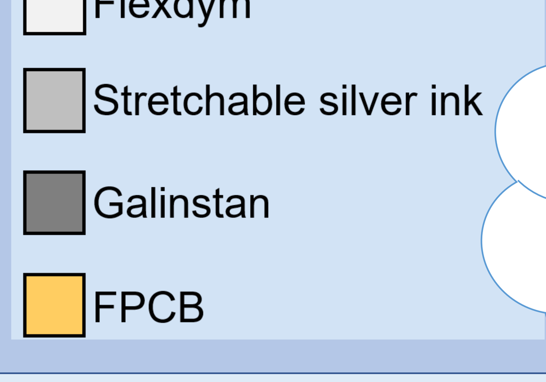
Length increases by **60-100%**

- Flaccid circumference: 9-10cm
- Erect circumference: 11-13cm

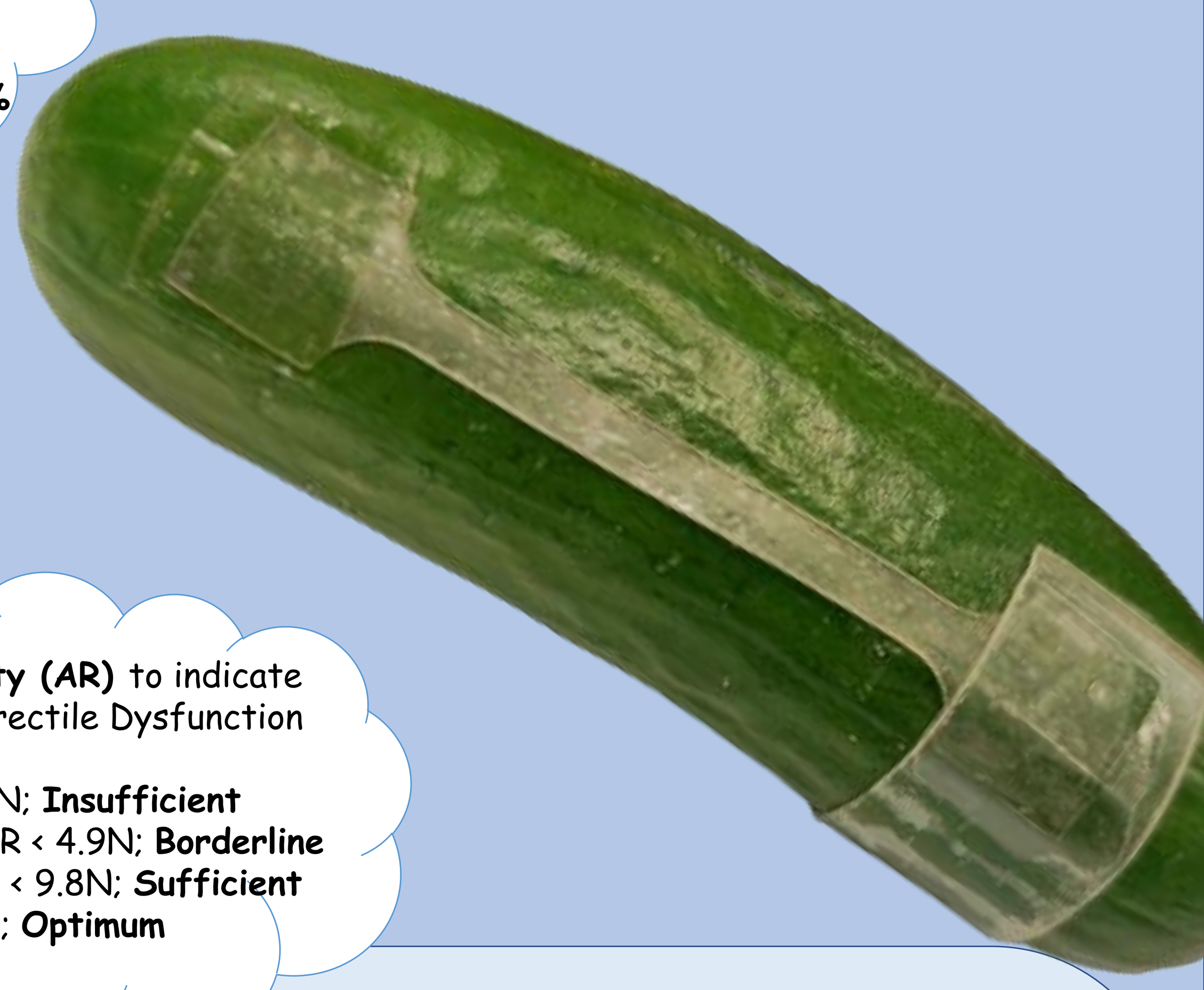
Circumference increases by **15-25%**

Sensor Fabrication Process





Step 1: Flexdym is extruded into a thin elastic sheet
Step 2: Silver ink is screen-printed to form strain gauges
Step 3: FPCB is attached for modular interfacing
Step 4: Patch is encapsulated with a second Flexdym layer



Axial Rigidity (AR) to indicate degree of Erectile Dysfunction

- AR < 3.92N; **Insufficient**
- 3.92N < AR < 4.9N; **Borderline**
- 4.9N < AR < 9.8N; **Sufficient**
- AR > 9.8N; **Optimum**

[4]

Results

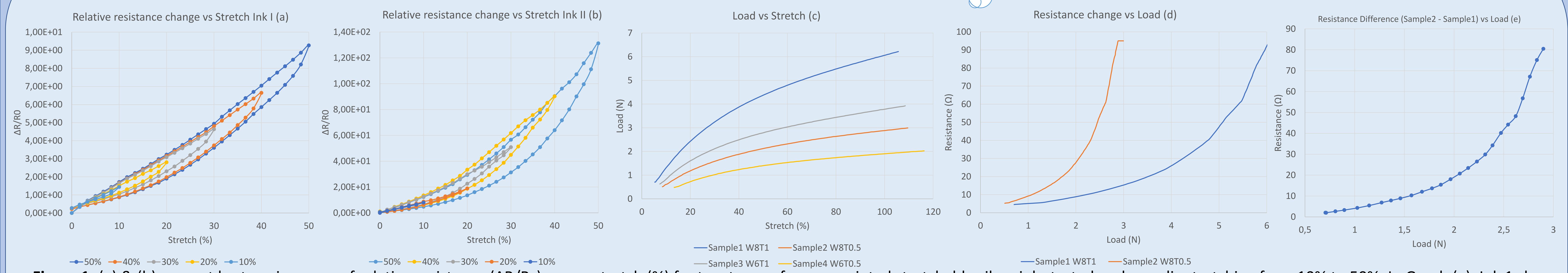


Figure 1: (a) & (b) present hysteresis curves of relative resistance ($\Delta R/R_0$) versus stretch (%) for two types of screen-printed stretchable silver inks tested under cyclic stretching from 10% to 50%. In Graph (a), Ink 1 shows a moderate response with a maximum resistance increase of around 9×. Graph (b) highlights the high sensitivity of Ink 2, which shows a dramatic increase of up to 130×, making it more suitable for applications requiring detection of fine strain changes. (c) displays Load vs Stretch (%) for four printed samples using Ink I with varying widths (6 mm and 8 mm) and thicknesses (500 µm and 1000 µm), measured using an MTS tensile tester. The results show that increased cross-sectional area (both width and thickness) leads to greater resistance to deformation, as reflected in the higher force required for the same amount of stretch. (d) shows Resistance vs Load for two samples printed using Ink I with the same width (8 mm) but different thicknesses. The sample with 500 µm thickness exhibits a steeper resistance increase, as it stretches more readily under applied load, leading to a greater strain-induced resistance change. (e) plots the resistance difference (Sample 2 − Sample 1) both printed with Ink I as a function of load, for the same samples shown in (d). Within this range, the resistance difference increases consistently with load, reflecting the higher strain sensitivity of the thinner (500 µm) sample. This zone captures the most responsive region before saturation effects become prominent.

Discussion

- **Ink composition affects response:** Ink 1 (silicone-based, silver flakes) offers high stretchability (~100%) and low resistivity, providing stable cyclic performance. Ink 2 (thermoplastic, fine silver particles) achieves sharper resistance changes (~130×) due to a more brittle, high-coverage conductive network.
- **Durability vs sensitivity trade-off:** Ink 2 is more responsive but less stable across cycles. Ink 1 shows smoother, repeatable signals, making it suitable for cyclic applications.
- **Hysteresis context:** While hysteresis limits long-term use, it's acceptable for single-event diagnostics like penile tumescence testing.
- **Geometry influences strain transfer:** Thinner sensors stretch more under identical load, yielding steeper resistance increases — key for strain amplification.
- **Diagnostic principle:** Resistance difference between thick and thin sensors increases with load due to bending, serving as a mechanical indicator of axial rigidity.
- **Design takeaway:** Material and geometry tuning enables passive, non-invasive sensing tailored for erectile dysfunction monitoring.

Conclusion

The printed strain sensors developed here show tunable sensitivity based on ink type and geometry, which is crucial for accurate, non-invasive monitoring of penile axial rigidity in nocturnal penile tumescence (NPT) tests. The findings validate a materials- and structure-driven approach for designing stretchable sensors in urological and erectile dysfunction diagnostics.

Future Work

Further work will target improved sensor reliability during real NPT cycles, optimizing form factor for skin adhesion, and integrating wireless modules for home-based monitoring. Advanced signal processing will also be explored to extract meaningful rigidity metrics, enabling a complete wearable platform for patient-specific erectile function assessment.

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Useful Links

1. https://eden-microfluidics.com/flexdym-microfluidic-chips/
2. https://www.dycotecmaterials.com/products/stretchable-inks/
3. https://www.uhasselt.be/nl/info-voor/bedrijven-en-organisaties/technology-offers/tumescence-measuring-wearable-patch
4. https://www.jessazh.be/web/international-network-penile-implant-surgery-eng/erectile-dysfunction
5. https://www.uhasselt.be/en/onderzoeksgroepen-en/imo-imomec-fme