

HYDROGEL ACTUATED MICRONEEDLE (HAM) WOUND PATCH

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Chronic wounds impact over 6.5 million individuals in the United States annually, with treatment expenditures exceeding \$25 million [1], [2]. A highly efficient intrinsic host defense mechanism monitors and repairs wounds in a timely organized manner. However, certain conditions, such as poor circulation, neuropathy, diabetes, difficulty in moving, and repeated mechanical force/stress, might interrupt the wound healing phase leaving it unresolvable for several months [2], [3]. Regrettably, present wound healing treatments frequently overlook the state of the wound. To enable appropriate adjustments to the wound, we present a novel wound state-responsible patch using pH-sensitive hydrogel as a base actuator that lifts a microneedle array for a self-adjusted wound stimulator (Fig. 1).

The pH of the skin is normally between 4 and 6, which is slightly acidic, providing better resistance against pathogenic bacteria. In contrast, chronic wounds raise pH up to 10 (basic), promoting bacteria growth more easily [2][3]. The proposed hydrogel actuated microneedle (HAM) wound patch utilizes these pH fluctuations caused by the wound's condition. As illustrated in Fig. 2, the HAM wound patch consists of a hydrogel as base block and a microneedle array as a movable plate, constrained in a 3D printed flexible patch. The pH changes due to wound state activate the hydrogel layer and swell in acidic pH or shrink in basic pH. Since the hydrogel is constrained, such chemomechanical actuation exerts to the opening side where the microneedle array plate is placed. This actuation poses the microneedle deeper into the chronic wound (higher pH), inhibiting bacterial activity and stimulating epithelial cells. Upon the wound recovering from the chronic condition, microneedles are retracted as is dictated by the pH level. Fig. 3 illustrates the fabrication procedure. The hydrogel is prepared by mixing acrylamide (AAm, Sigma) with methacrylic acid (mAA, Sigma) along with tetramethyl ethylenediamine (accelerator, Sigma) and N,N'-methylenebisacrylamide (crosslinker, Sigma). A 3D-printed flexible patch is created consisting of an array of one or more rectangular cells ($2 \times 2 \times 3 \text{ mm}^3$), and each cell is filled with a 1mm thick hydrogel. During curing, a microneedle platform, treated with γ -Methacryloxypropyltrimethoxysilane 99.04% (MPS) solution, is placed on top of the hydrogel. The MPS treatment promotes the adhesion between the hydrogel and the microneedle platform. To retain the microneedle platform within the patch, a stopper is added.

To validate the pH-sensitive actuation, the prototype patch is exposed to several pH solutions (Fig. 4). After presoaking in DI water (pH 7), which swells hydrogel to the baseline of 2-mm height. (Fig. 4a), the chronic wound environment is mimicked by introducing pH 10 solution. Fig. 4b shows the pictures of the HAM patch during 90 minutes of swelling. To increase visibility, the hydrogel was treated with phenol red indicator dye, and photos were taken every 60 seconds over 90 minutes. As seen, the hydrogel gradually grows and lifts the microneedle array upward (note that we inverted the HAM patch for experimental convenience). During the actuation, the force is also measured using a force meter (Torbal). The small dimension of hydrogel bases ($2 \times 2 \text{ mm}^2$) exerted the highest force (262 mN), while the larger dimension ($4 \times 4 \text{ mm}^2$) showed almost no force even though some swelling was observed (Fig. 5). The measured force exceeds the reported required force for skin penetration (250 mN) [4]. After the force measurement, the total displacements of microneedle penetration were measured, which is shown in Fig. 6. The overall growth translates to 2.1 mm height, which allows the full extrusion of the needle into the wound.

Word count: 582

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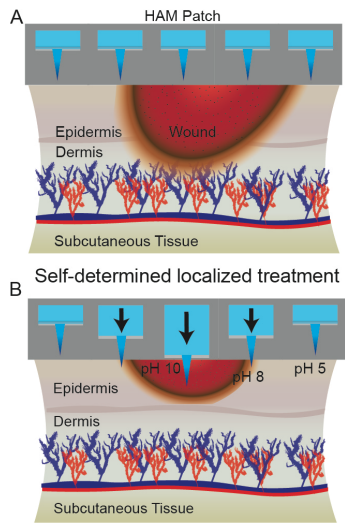


Figure 1: HAM device self-adjusting within the tissue (A) Initial application to wound (B) Microneedles responding to higher and lower pH values

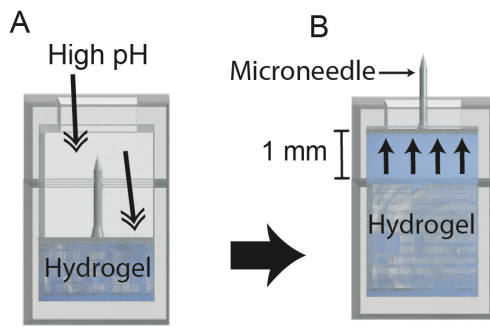


Figure 2: (A) Single cell of the HAM patch introduced to pH 10 solution, (B) resulting swelling of the hydrogel

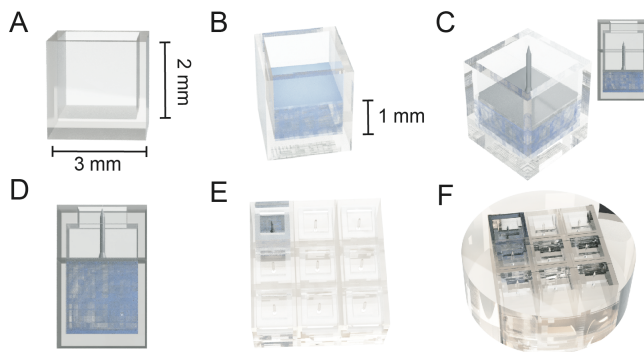


Figure 3: Fabrication of one cell of the HAM patch, (A) soft 3d printed HAM cell, (B) case is filled with 1mm thick hydrogel solution, (C) microneedle is placed on the curing hydrogel, (D) stopper application to casing, (E) curing hydrogel, (F) final HAM cell

Final HAM device with 9 cells, (F) HAM cells inside of circular patch.

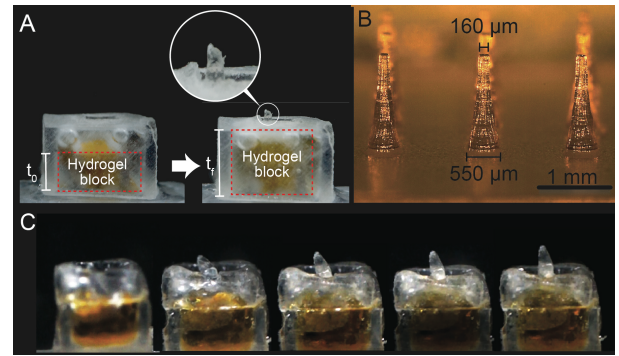


Figure 4: (A) Side view of the HAM cell before and after hydrogel expansion and the microneedle is extruded. (B) macro-picture of microneedle. (C) HAM cell during extrusion

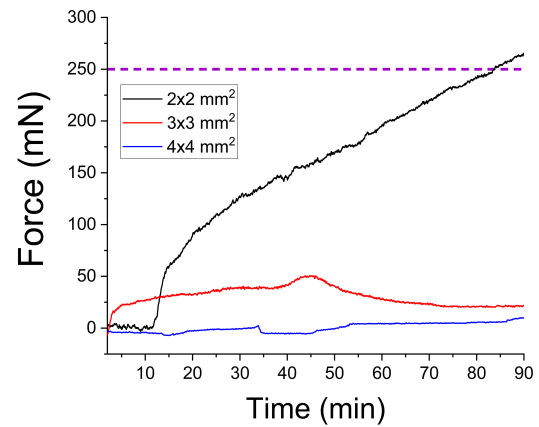


Figure 5: Force measurements for three hydrogel dimensions

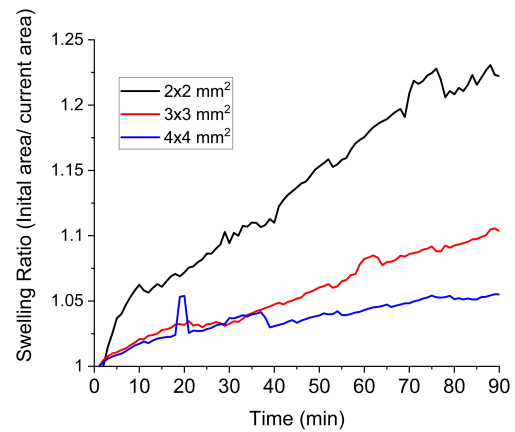


Figure 6: Swelling ratios comparison for the swelling of three hydrogels.