ACTUATED WOUND SENSING, CLOSING AND HEALING IN FLEXIBLE SHEETS USING FUNCTIONAL MACRO CELLS

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ABSTRACT

This paper describes an examination and demonstration of a flexible sheet system based on a functional macro-scale architecture that detects and localizes cutting damage, closes the wound through mechanical actuation, repairs the cut with healing liquids that solidify in the cut. Following sensing of successful healing, the system deactivates the wound closing and other healing processes. The building block of this system is a functionalized multicellular structure where each cell has the ability to sense through-sheet cut damage, actuate bi-directional in-plane deformation, dispense and cure a healing liquid, and communicate with neighboring cells. The cellular architecture enables varying the type and testing the performance of individual sensing, actuating and healing techniques; along with examining the behavior collective multicellular behavior, such as pursestring wound closing. This system represents a highly simplified mimic of some of the wound healing processes occurring in biological system. One demonstrated variant uses a neoprene skin with embedded subsurface optical sensing, electromechanical in-plane actuation, localized microprocessor control and actuated dispensing of neoprene-specific healing liquids embedded in each cell. Additional techniques presently under investigation are aimed at miniaturizing the cells and enabling a more facile response. These include active solids and constrained gels for in-plane deformation, finer-pitch healing liquid distribution with vascular or wet-sublayer configuration and different spatial gradient collective multicellular healing control.

1. INTRODUCTION

Wound closing is a macroscale healing technique commonly used in biological systems. Wound closing generally alters the mechanical stress and material distribution in the tissue surrounding a wound so as to shrink the size of the open damaged area. The advantages for wound closing are: 1. The contraction reduces the volume and area of the wound to be healed. 2. The closed wound requires less material for a more substantial healing, including subsurface structures. 3. Closing the wound reestablishes the barrier between the interior and the exterior of the system. Tissue swelling along with infilling and circumferential hoop contractions acts to close the wound. Plants, animals and even single-celled creatures routinely close wounds. A surgeon’s stitches assist wound closing by exerting tension across the wound. Biological systems use other mechanical techniques, such as ‘purse string’ tightening.
Self-healing material and structural systems technology has seen considerable development in the past two decades. Much of this activity has addressed the topic of repairing tight cracks through polymer merging or the release of embedded and encapsulated liquid healing agents. Coordination can enhance self-healing performance by making more efficient use, storage and allocation of healing resources [1]. Coordinated self-healing can use virtually all of the techniques described above, while taking advantage of sensing coordination, decision making, actuation and monitoring. Coordination also includes sensing of damage and actuating repair terminating and modulating repair as it progresses, and actively directing construction of new structural forms. This paper examines the related, but relatively unaddressed problem of autonomic wound closing methods. When the damage is moderate to severe, closing the wound as a first step can enable tight crack healing methods to work with greater efficiency and ease. Closing or filling the gap with material compatible to the original material and restoring the smooth flow of stress and strain across the crack.

Wound closing requires shape control. A variety of tools are becoming more readily available that enable controlled altering of the shape of materials. Shape memory materials can return to an original following an extended period of large inelastic deformation, often with the aid of thermal cycling [2]. The heat-induced swelling of intumescent materials can alter the connectivity of structural components and significantly delay or arrest the progress of fires or extreme heat. Dielectric elastomers can induce large deformations under control, but the required geometries and large voltages presently limit the range of applicability. Microstructure-actuated snapping surfaces are another possibility. Compliant arrays of flexure mechanisms can aid integrating shape changing methods into structural systems. Liquid-induced swelling can cause autogenous crack sealing. This requires a material that swells when the liquid penetrates into the crack. Miccichè et al. [3] resolve the issue with a water/humidity-induced swelling of a subsurface layer of montmorillite clay layer.

Methods of wound closing in engineered systems include: 1. 2-D Purse String Method – The purse string method acts on planar structures. A tension ring, i.e. knittle, forms around the wound. Inside the knittle swelling induces compression, which closes the wound. Figure 1 shows the concept; 2. 3-D Constrained Layer Swelling – The swelling of material for wound closing is much more effective when the swelling is constrained by stiff layers [4]; 3. 3-D Out-of-Plane Delamination Closing – Delaminations between layers in a material system can be closed by out-of-plane forces perpendicular to the plane of the delamination; 4. Bridging and Stitching Across the Wound – Fibers that bridge and then pull across the gap can be effective at closing the wound [5]; 5. Sliding and Covering – This is an autonomic band-aid technique that slides a prepositioned protective layer across the wound.
2. MATERIALS AND METHODS

Figure 2 shows a test rig and results of a cellular actuated purse string method developed to demonstrate autonomic wound closing through a multistep process of injury sensing with embedded optical sensors, followed by solenoid-actuated wound closing, then the dispensing of a neoprene-specific healing fluid and curing to seal the wound.

Figure 2: a. bottom side view of autonomic wound closing mechanism, b. solenoid actuation schematic, and c. cellular pneumatic concept for multi-site repair under development.

3. RESULTS AND DISCUSSION

Figure 3.a shows the results of a finite element analysis of the wound closing system. Figure 3.b shows successful closing and repair of a cut into the neoprene skin. Extending this technique to large regions requires spanning an external skin surface with multiple repair mechanisms.
Figure 3: Cellular mechanical wound closing test rig developed at UVM a. Backside sensing and actuation mechanism, b. Conceptual model, c. Numerical model, d. Wounds closed and then healed in neoprene skin, e. Plan for scalable multi-celled system.

4. CONCLUSION

The actuated wound closing then healing method has been demonstrated. The present system is somewhat bulky, but may be miniaturized and packaged in a way to be practical for future applications.

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REFERENCES