Mini Review
Volume 14:12, 2022

Journal of Bioanalysis & Biomedicine

ISSN: 1948-593X
Open Access

A Look at the Bio-Inspired Needles Used for Percutaneous Procedures

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Abstract

The knowledge of natural or biological structures or behaviors is translated into novel theories and technologies through bio-inspired design, providing fresh research and development avenues. Biomimetic solutions are becoming increasingly popular to enhance the performance of medical needles, despite the fact that the technology for percutaneous intervention medical needles appears to be mature. Bio-inspired medical needle designs for percutaneous interventions, including a variety of biomimetic mechanisms and insertion strategies, are reviewed in this paper. The applications of the various biomimetic medical needle designs, as well as the characteristics of those designs, are categorized into five groups and discussed. In addition to providing technical insights into previous studies, this sort of classification and discussion will reveal previously unknown directions for subsequent research.

Keywords: Biological structures • Biomimetic solutions • Needle designs

Introduction

Modern medical procedures and treatments frequently employ percutaneous interventions. The insertion of needles, catheters, and probes into the patient's bodies and tissues is necessary for the percutaneous diagnosis and treatments, such as brachytherapy, blood sampling, and biopsies. In order to achieve the desired outcomes with percutaneous devices, there are numerous requirements and precautions. Specialized needles are designed and developed for signal monitoring, drug and vaccine delivery, and bio-sensing, in addition to those used in common percutaneous interventions. However, a number of issues and disadvantages have been identified in the current design of medical needles, prompting researchers to seek innovation and improvement [1].

Mechanical errors like tissue deformations and needle deflections caused by the bevel tip, in addition to imaging limitations, image misalignment, target uncertainty, and human errors, can severely undermine the accuracy of needle placement, compromising the therapy's efficacy [2,3].

Description

Tissue deformations and movements are still uncertain and difficult to predict, despite the fact that active needle control can improve placement accuracy. In stereotactic core biopsy of breast tissue, it has been reported that tissue deformation and needle displacement can result in a positioning error of up to 2.4 millimeters. The typical insertion of a rigid needle deforms and moves both the target and the soft tissue, invalidating the planned path. Additionally, insertion behavior varies depending on the needle's tip characteristics. The reaction force on the asymmetric tip causes the bevel-tip needle to deflect during insertion, resulting in an undesirable insertion trajectory and affecting insertion accuracy, despite the fact that the commonly used bevel-tip needle is associated with less insertion force than the conical-tip needle.

A reinsertion or intraoperative path adjustment must be considered when the needle is misplaced for the aforementioned reasons, resulting in complications for both the patient and the physicist. However, since most needles are rigid, it is unlikely that the needle will need to be readjusted after the insertion has been completed. In addition, some targets are difficult to reach, such as the vessels and organs on the path. The physicist may be forced to perform open surgery with standard rigid needles, which could complicate the treatment. It seems that standard rigid needles can't steer, which limits where the needle can go. As a result, a design for flexible needles may provide a means of enhancing needle adjustment and maneuverability for more precisely reaching the target.

In addition, the goal of minimal invasiveness is undermined by the large force of the needle's insertion, which can result in soft tissue damage and pain for the patient. Previous research demonstrated a positive correlation between the patient's pain and the force used to insert the needle. As a result, a key to painless therapy is lowering the force of insertion. In addition, if the force of the needle is not controlled, it can cause injuries during brain surgery and damage soft tissues like the brain. In order to reach the deep target in many percutaneous procedures, a long, thin needle is typically required. However, when penetrating a solid substrate, a large insertion force causes a large axial stress on the long and thin needle, likely resulting in buckling. Buckling prevents needle performance and raises safety concerns by limiting the depth of penetration and resulting in inaccurate insertion [4,5].

Conclusion

Long-term tissue adhesion becomes one of the challenges in some medical situations like sustained drug delivery, innate wound healing, sensor or microrobot anchoring, and even the deployment of bandages. The use of cyanoacrylate, for example, is one of the developed chemical adhesion methods that has the potential to trigger an inflammatory response in the tissue. Additionally, the strengths of chemical bondings can be easily tainted by the presence of blood, posing safety and health risks and reducing the adhesion's effectiveness in numerous surgical settings. Additionally, the dependability of long-term drug delivery is compromised by weak and ineffective tissue adhesion. Although adhesive tapes were designed to shorten procedure times, minimize scarring on the tissue, and distribute

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Received: 02 December 2022, Manuscript No. jbabm-23-87400; **Editor assigned:** 04 December 2022, PreQC No. P-87400; **Reviewed:** 16 December 2022, QC No. Q-87400; **Revised:** 21 December 2022, Manuscript No. R-87400; **Published**: 28 December 2022, DOI: 10.37421/1948-593X.2022.14.359

forces across a larger area, their ability to adhere to the tissue is still not ideal in many situations due to the fact that their adhesive mechanism relies solely on surface entanglements rather than penetrating the tissue.

Acknowledgement

None.

Conflict of Interest

None.

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How to cite this article: Ren, Hongliang. “A Look at the Bio-Inspired Needles Used for Percutaneous Procedures." *J Bioanal Biomed* 14 (2022): 359.