Real-Time Measurement of Jet Penetration

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Introduction

Needle-free jet injection (NFJII) is a promising alternative to hypodermic needle drug delivery. NFJII carries no risk of disease transmission, and is preferable to needle-phobics. However, many NFJII systems suffer from a lack of reliability in terms of drug delivery depth and dosage. Real-time control of jet penetration depth during jet injection has been proposed as a solution to improve the reliability of NFJII. This project examined the use of real-time depth measurement in tissue-mimicking gel to determine the feasibility of depth-based control methods for needle-free jet injectors.

Development

In order to detect the penetration of a jet through gel, a custom laser break beam sensor was designed and fabricated. This sensor used a set of cylindrical lenses to shape a laser beam into a wide and narrow sheet through the gel sample. A photodiode collected the beam and measured sample absorbance at a specific detector level. A high-speed digital controller was used to monitor photodiode output, in order to determine the point at which a jet had penetrated to the target depth.

Real-Time Control

The dynamics of real-time depth control for jet injection were investigated by integrating the break beam sensor with a controllable ABI jet injector. Injections were then performed into polyacrylamide gel samples. Injector voltage was gradually increased over the experiments, which resulted in increased jet velocity.

Injections were recorded using a high-speed camera at a frame rate of 20,000 FPS. Positional data was also recorded and logged by the control system to allow analysis of the injector behavior. The injector control system was configured to either stop, or reverse the direction of piston movement once the jet had reached a target depth.

Results

- The response time of the detection system was measured using high-speed video imaging, and verified to be less than 50 µs.
- The break beam sensor was able to control the penetration depth of an injection to within 2 mm of a target depth, regardless of jet velocity.
- Reversing the piston was found to have no benefit compared to stopping the piston.
- Removal of air from the injection reservoir, as well as the use of a stiff piston, resulted in improved jet dynamics.
- Polyacrylamide gel mechanics may have contributed to the variation in jet penetration depth.

Conclusions

- A laser break beam sensor was developed and integrated with an ABI jet injector, allowing real-time depth-based feedback control of jet injection.
- Feedback control was able to control jet penetration depth, independent of jet velocity.
- Further work is required to develop a system for tracking penetration depth in tissue.