Proceedings of the Canadian Society for Mechanical Engineering International Congress 2021
CSME Congress 2021
June 27-30, 2021, Charlottetown, PE, Canada

Dynamics of Drug Delivery via Needle-Free Pneumatic Jet Injection

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ABSTRACT

Despite its long history and widespread applications, the mechanisms of needle-free injection remain poorly understood. An enhanced understanding of the fluid flow and drug transport is needed to elucidate the exact location of the injected drug in various tissues. This may improve outcomes by informing optimized clinical techniques. Increased uptake associated with better outcomes may then benefit clinicians via decreased risk of needle-stick injuries and transfection, and patients by providing an alternative which reduces needle phobia and related avoidance of medical procedures in some patients. In this study, we characterized a needle-free liquid jet injection (NFLJI) device (MED-Jet, MIT Canada Inc., nozzle diameter 50 μm) using dental local anesthesia as a clinical test case. A tissue phantom was first developed based on characterization of porcine oral mucosa mechanical properties and porosity via rheometry and scanning electron microscopy. It was found that type-II bovine gelatin (5% mass concentration) approximated the modulus and viscosity of porcine oral mucosa, but the injection wound morphology differed from that of tissue. A polyhydroxyethylmethacrylate (pHEMA) phantom better reproduced the porosity and wound morphology of tissue. Needle-based and jet injection using a customized test apparatus comprising a strain gauge transducer, a motorized traverse, and a high-speed camera. Output parameters included injection forces and energy, and wound morphology. The effects on NFLJI of injection volume (0.1-1 mL) and pneumatic supply pressure (413.7-1241.1 kPa), and on needle injection of insertion speed (2-37.5 mm/s), needle geometry (18-27 gauge, flat and bevel-tip), injection volume (0.3-1 mL), and flow rate (0.9-7.2 mL/minute) were characterized. For needle insertion, bevel-tipped geometry and increased needle diameter produced decreased insertion forces. For needle injections, increased volume produced greater force and impulse. Increased flow rate decreased impulse, but increased injection work. For NFLJI, increased volume increased force, impulse, and work. Increased supply pressure increased impulse, work, and force amplitude at 0.1 mL and 0.3 mL, and jet penetration depth at all volumes. Needle injection and NFLJI produced comparable forces; however, the duration of NFLJI was shorter. While injection work was comparable for some configurations, a 1 mL injection produced greater energy via NFLJI, suggesting greater tissue damage. Clinical investigations have associated decreased pain with NFLJI, indicating that temporal aspects of injection pain sensation may dominate energetic aspects. These results are used to inform clinical pilot testing of NFLJI for local anesthesia at the McGill Dental Clinic. They will help define clinical guidelines for widespread NFLJI use.

Word count: 399