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Injection Dynamics of Needle-Free Liquid Jet Injection

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ABSTRACT

Needle-free injection is a well—established technology with widespread applications, but its detailed mechanism is poorly understood. Thorough investigation of this mechanism will assist in comparing its efficacy to needle-based injection and inform evidence-based clinical techniques. Improved technique may benefit patient outcomes, increasing uptake and benefiting clinicians via decreased risk of needle-stick injuries and transfection, and patients by providing an alternative which reduces needle phobia and related avoidance of necessary medical procedures in some patients. In this study, we characterize a pneumatic needle-free liquid jet injection (NFLJI) device (MED-Jet, MIT Canada Inc., nozzle diameter 120 μm) for use in dental local anesthesia. A tissue phantom was first developed based on the mechanical properties and porosity of porcine oral tissue, characterized via rheometer and scanning electron microscope (SEM). Type-II bovine gelatin hydrogel (5% mass concentration) approximated the modulus and viscosity of porcine oral mucosa, but the injection wound morphology differed from that observed in tissue. A polyhydroxyethylmethacrylate (pHEMA) hydrogel phantom better reproduced the porosity and wound morphology of porcine oral tissue. These phantoms were used to compare injection via needle and NFLJI on a test apparatus comprising a strain gauge transducer, motorized traverse, and high-speed camera. Injection modalities were compared based on injection forces, 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. In needle insertion, bevel-tipped geometry and increased gauge produced decreased insertion forces. In needle injections, increased volume produced greater injection forces and impulse. Increased flow rate decreased impulse, but increased injection work. In NFLJI, increased volume increased injection force, impulse, and work. Increased supply pressure increased impulse, work, and force at 0.1 mL and 0.3 mL, and 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 clinically-relevant 1 mL injection produced greater energy via NFLJI, suggesting greater tissue damage. Clinical investigations have associated decreased pain with NFLJI, which may indicate that temporal aspects of injection pain sensation dominate energetic aspects. These results informed clinical pilot testing of NFLJI for local anesthesia at the McGill Dental Clinic, and will help define clinical guidelines for safe use of NFLJI systems.

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