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FIBER BRAGG GRATING BASED FORCE SENSING NEEDLE

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Introduction: Little is known about the mechanics of needle-tissue interaction during percutaneous interventions in deep-seated parts of the body. The forces arising from this interaction are influenced by numerous factors, such as needle type, tissue characteristics, and insertion speeds. Reliable experimental data is essential for the development and validation of theoretical models that describe these forces. However, the various factors can all have different influences on the forces that make up the total force acting in the direction of insertion. The axial force consists of puncture forces, cutting forces, and friction forces and these cannot be measured separately from outside of the body. The current study focuses on the development of a needle that has force sensing capabilities at the tip to be able to measure only the puncture and cutting forces during insertion.

Methods: The developed needle is build up from a commercially available 20cm long trocar needle. The needle has an inner core with a diameter of 1mm and an outer shaft of 1.3mm. For the current design, the inner core was replaced by a steel tube to enable passing of an optical fiber. The optic fiber carries a Fiber Bragg Grating (FBG) that was embedded in a PVC element implemented close to the tip of the needle. Variations in the spacing of the grating due to strain changes induce variations in the index of refraction and thereby shift the wavelength of reflected light. Wavelength-division multiplexing (Deminsys, Technobis) can be used to measure such changes in wavelength at the other end of the optic fiber, and enables direct measurement of tip forces from the outside of the body. A tensile testing device (Zwick) was used to determine the relationship between wavelength shifts and axial tip forces within a range of zero to 10N. The force sensing capabilities of the needle were further evaluated in a phantom model that consisted of multiple layers of gelatin to mimic various tissue layers.

Results: Calibration of the needle based on the Zwick data revealed an absolute average error of less than 0.1N in the measurement of the force that was exerted on the tip of the needle. Subsequent experiments showed that the needle was sensitive enough to detect the passing of the needle through the boundaries between the different layers of the phantom model.

Discussion: FBG-based strain measurement enables safe and direct force measurements at the tip of percutaneous instruments of miniature dimensions. The possibility to reliably measure puncture and cutting forces separately from friction forces supports the development of new types of needles, needle-insertion simulators, and needle-insertion robots for use in a clinical environment.