Computer Aided Radiology and Surgery (CARS), Berlin, June 20-23, 2018.

In Situ Augmentation of Force and Torque Perception using Patient-Based Forces.

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Keywords: robotics, microsurgery, haptics, augmentation

Purpose

Our goal is to increase the clinician's touch sensitivity and enable more precise control in situations where tactile or visual feedback is limited, thereby improving procedural outcomes. Microsurgery, or any other manipulation of fragile, flexible, or hidden tissues, mandates extremely high technical skill, surgical acuity and precision. If tactile feedback could be amplified during such procedures, tissue trauma could be minimized, operator efficacy maximized, and techniques optimized.

We have created designs for a new device to address several such clinical applications, including Difficult Venous Access (DVA). Veins may be difficult to access for a variety of reasons, and we specifically address the tendency for some veins to roll, especially in pediatric patients, where it may prevent as many as 5% of patients from receiving placement of peripheral intravenous lines essential for treatment of dehydration, septic shock, or trauma [1].

Methods

We have previously developed a technology we call the Hand-Held Force Magnifier (HHFM) [2,3]. This technology augments forces detected at the tip of a tool with forces exerted on the tool handle by an actuator connected to a brace on the back of the operator's hand. It does so in-situ, meaning the operator interprets the augmenting forces as coming from the tip of the tool, superimposed on the original forces [4,5].

Our innovation falls into the category of Cooperative Robots, meaning that, as opposed to telerobotic systems such as the da Vinci Surgical System, the robot directly affects the same tool as the clinician, in our case by exerting forces that augment those already present from contact with the patient.

Prior tactile augmentation systems used a robotic arm to hold the surgical tool simultaneously with the surgeon, pushing and pulling as appropriate. Because every force needs an opposing force, the robotic arm was mounted on the floor or table-top. The HHFM freed the operator from such an external ground by using the back of the operator's hand as a reference instead.

We now adapt the HHFM approach to use passive forces generated relative to the patient rather than the operator's hand, in what we call the Patient-Based Force Magnifier (PBFM). This provides a number of significant improvements over the HHFM:

(1) The augmenting forces now exist outside the hand, so that the operator's upper arm and shoulder also experience actual force augmentation, rather than the illusion of such as in the HHFM.

(2) The platform resting on the patient can be significantly larger and heavier than a typical surgical tool, permitting generation of larger forces and providing a firmer base against which to generate them.

(3) Since forces are now generated nearer the distal end of the tool, leverage problems with non-axial forces and torques in the HHFM are avoided.

(4) Since the augmenting force and torques need never be greater than those being applied by the surgeon, we may simply impede the intended motion so as to increase the force or torque required by the surgeon to move the tissue. This can be accomplished by a brake or variable-compliance linkage instead of an actuator, and in some cases, a single variable-compliance linkage may replace multiple independent actuators.

(5) Eliminating the brace frees the surgeon to shift his/her grasp on the tool and to switch tools more easily.

In addition, we have replaced the embedded force sensors used in the original HHFM to inform the force augmentation with real-time imaging (ultrasound and optical coherence imaging) to detect tissue motion or deformation. Along with the removal of the hand brace, this frees us to use standard surgical instruments, a significant advantage for introducing the technology into clinical practice.

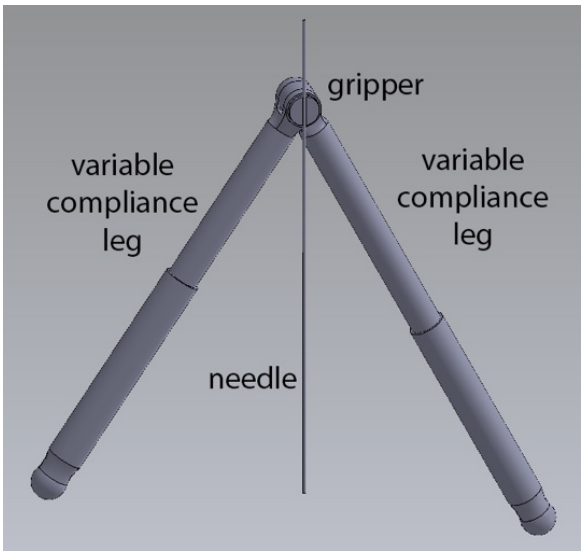

Figure 1. Patient Based Force Magnifier (PBFM) configuration for Difficult Venous Access (DVA).

Results

Figure 1 shows a PBFM device for rolling veins, which rests on the patient, through which the needle passes before reaching the skin. The legs contain variable-compliance actuators, allowing each leg independently to be stiff or to act essentially as a variable-compliance spring. The device also contains a gripper that can engage the needle, or let it freely pass. Initially the needle is allowed to pass by the gripper. The legs are both initially stiff. When the needle reaches the vein, the vein may move laterally (roll) rather than submit to puncture. We detect this lateral motion relative to the surrounding tissue by automated analysis of an ultrasound image, at which point the gripper engages the needle and one or the legs becomes compliant while the other remains stiff. Which leg becomes compliant depends on the direction of the roll. Figure 2 shows how having the left leg become compliant causes a shift of the needle (from solid to dashed lines) to track the vein to the right, with the entry point through the skin acting as a fulcrum. The effect of this will be for the operator to feel a tendency for the needle to move in the correct direction to follow the rolling vein, as if finding a soft spot in the vein that guides the needle tip along its path of least resistance. We hypothesize that it will feel as if the needle had a rounded tip and were finding a hole, whose edges were sloped to guide it in.

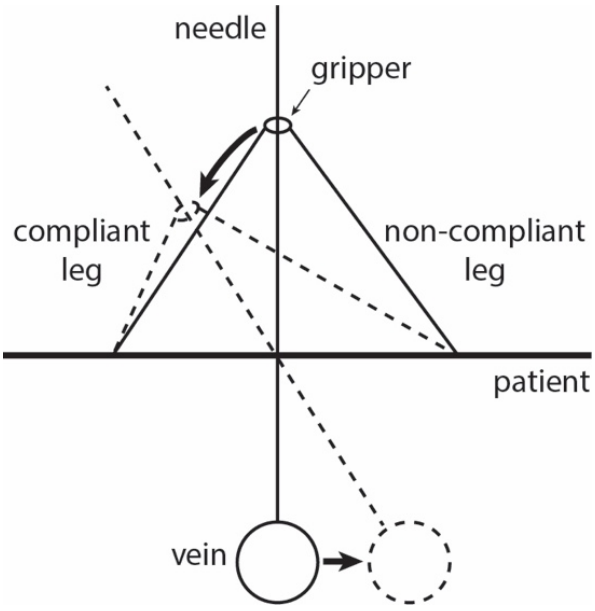

Figure 2. Patient Based Force Magnifier (PBFM) geometry for following mobile vein.

We expect to be able to detect puncture of the proximal wall of the vein in the vertical motion of the vein in the ultrasound image. At that point, with the gripper maintaining its hold on the needle, the PBFM device will lock both of its legs into a non-compliant configuration. This will present the haptic illusion of a stiff boundary at the distal wall, preventing its puncture and associated vessel damage.

Conclusion

Although our innovation is at an early stage, we believe the underlying concepts are important and novel enough to be of interest to the community. We have submitted a patent application, and hope to be able to report more results in the near future.

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