Observations of Lightly Flexible Needle Deflection in 3D CT/MRI*

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Abstract— Singular challenges associated to ARCS (Abdomino-pelvic Robotic-driven lightly flexible needle insertion performed in CT/MRI-guided Scenario), make difficult to incorporate most of the existing needle deflection modeling approaches, not originally conceived to this context. This paper addresses the issue by proposing observation and study of percutaneous insertion experiments under a robotic platform compatible to ARCS. Study and observations of 3D reconstructions obtained from experiments of percutaneous insertion in soft tissues are presented in this work. Design of experiment setup allowed the building of a procedure´s database which is an important step to the compatible characterization of percutaneous procedures into ARCS.

Introduction. Numerous models for needle deflection prediction were proposed in the last years. Most of them were committed to improve the efficiency and consistency of needle path planning and steering, considering the several existent interventional robotic platforms [1] [2]. ARCS has special challenges associated to the bore size, radiation and ferromagnetic compatibility. Moreover, 3D real-time (RT) feedback isn't feasible in most standard CT/MR scanners today. All these issues limit the use of RT systems and conventional force sensors. It makes more difficult the application of most of the existing needle deflection modeling approaches not originally conceived for this particular scenario. Currently, 6-DoF LPR is the only robotic teleoperation platform that can perform needle translation, rotation and needle insertion in CT/MRI [3] [4] [5]. Generalist models conceived to other contexts and platforms don't fit directly to the ARCS' constraints [6] [7] [8] [9]. Meanwhile, more relevant efforts need to be committed to provide a compatible model that could be used in this complex context. This paper addresses the issue by proposing to create insertion experiments database involving this platform. The pilot database will be important to the design of a simulation model that could be compared to the results obtained in real case. First, we start presenting experiment setup, procedure and test samples. Then, we present and discuss result of the experiments committed to characterize 3D needle deflection inserted in soft tissues. Thirdly, we also tested mechanical properties of PVC and ex-vivo pork. Finally, we provide conclusions and recommendations for future works.

Methods. Experiments of robot-driven lightly flexible needle interacting with (10x10x13cm) PVC (100% soft plastisol) and ~(8x8x10cm) ex-vivo pork (1.5kg, supported by a plastic canister) tissues were performed using a LPR. A 6-DoF force-torque sensor (nano43 / SI-36-0.5 / ATI Industrial Automation) was mounted below the phantom and was used to track the resulting forces and torques on the phantom body. The force data were used to enrich the system's study and observations. They were not considered as input in the modeling. A framework support was built to fix the robot using two rigid plastic walls attached to a wood base (Figure 1A). The force sensor was fixed in this base, while an additional wood base was attached on the force sensor using screws (Figure 1B). The tissues were placed on this extra rigid surface (Figure 1C). The Figure 1D shows the robot's grippers (G1 and G2) holding the needle.

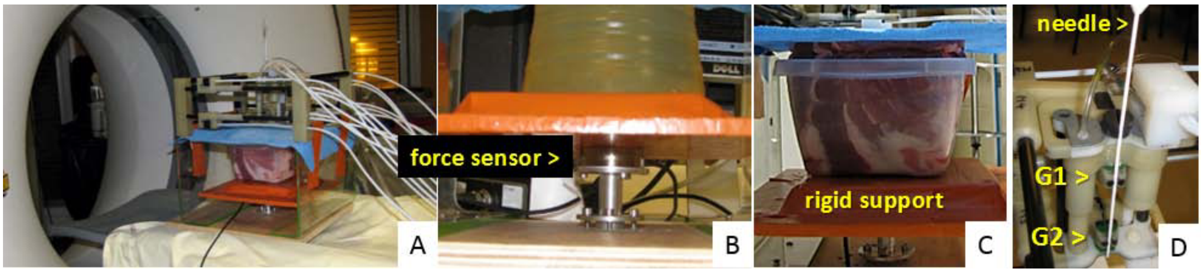

Figure 1. Experiment setup. A. Customized support framework. B. Force sensor C. Ex-vivo tissue pork. D. LPR´s grippers (G1 and G2) and needle.

Insertions were performed progressively into different tissues (100% soft synthetic PVC and in ex-vivo pork). The images were acquired using a Siemens Somaton Sensation 16 CT scanner at the CHU-Grenoble. They have dimensions of (512x512) (~200 slices/sequence) and voxel resolutions of (0.6x0.3x0.3mm). A database with 36 CT image sequences was created, related to thirteen insertion procedures and tests of the tissue properties scanned progressively. Vertical insertions as well as insertions inclined by 10 degrees in various directions were performed using a long (20 cm), 17 degrees bevel-tip spinal needles.

Results and Discussion. The setup's design presented in the previous section was motivated by the clinical challenges of ARCS. The experiment setup allowed the observation of 3D CT reconstructions and fiducials points (Figure 2A), obtained under submillimetric precision. Measurements of the axial and orthogonal needle deflection, as well as tissue deformation were performed. They will be used as ground truth for subsequent modeling and simulations. Deflections of the needle orthogonal to the insertion direction were observed in the range of 3-6 mm in both tissues for insertion depths of nearly 5-8 cm (Figure 2B). The tissue (stiffness) parameters (*Kt*) were obtained pre-operatively at surface level by axial compression tests as in ref [7], having the coefficients *Kt*(Homog)=490 N/m, Kt(2Layers)=115 N/m and Kt(4Layers)=130 N/m.

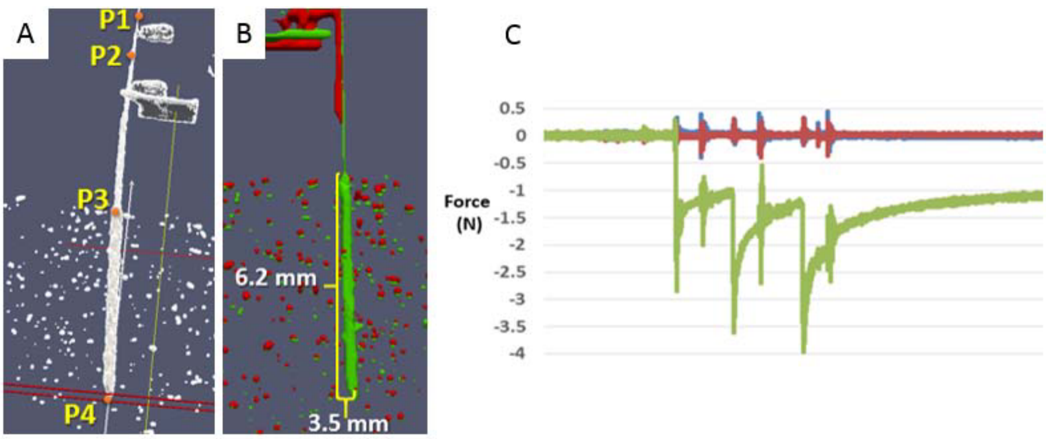

Figure 2. A: Fiducial points. B: Needle deflection sample. C: Transverse and axial force measurements into a insertion sample.

The force data (Figure 2C) shows the three insertion steps of a full insertion. It reveals occurrence of tissue relaxation. For the several samples, the relaxation stability was reached at nearly 1N, after some rest time between insertions. The observations and studies of the described experiments and database information gathered in this work provided a better comprehension of the mechanics of the lightly flexible needle inserted into soft medium. The information collected will be worthy in the implementation of a 3D model compatible with the unique constraints of this scenario and platform. Additionally, the experiment setup could be reapplied to gather more insertion samples to support a future validation approach.

REFERENCES

[1] M. Abayazid, M. Kemp and S. Misra, "3D flexible needle steering in soft-tissue phantoms using fiber bragg grating sensors," *In Proc. of ICRA - IEEE Int. Conf. on Rob. and Autom.,* pp. 5843-5849, 2013.

[2] H. Su, M. Zervas, G. Cole, C. Furlong and G. Fischer, "Real-time MRI-guided needle placement robot with integrated fiber optic force sensing," in *ICRA - IEEE Int. Conf. on Robt. and Autom.*, Shangai, 2011.

[3] E. A. Dorileo, N. Hungr, N. Zemiti, C. Fouard and P. Poignet, "A modular CT/MRI-guided teleoperation platform for robot assisted punctures planning," in *28th CARS - Computer Assisted Radiology and Surgery*, Fukuoka, 2014 (to appear in).

[4] N. Zemiti, I. Bricault, C. Fouard, B. Sanchez and P. Cinquin, "LPR: A CT and MR-Compatible Puncture Robot to Enhance Accuracy and Safety of Image-Guided Interventions," *IEEE/ASME Transactions on Mechatronics,* vol. 13, no. 3, pp. 306-315, 2008.

[5] N. Hungr, C. Fouard, A. Robert, I. Bricault and P. Cinquin, "Interventional Radiology Robot for CT and MRI Guided Percutaneous Interventions," in *MICCAI*, Toronto, 2011.

[6] R. J. Webster, N. J. Cowwan, G. S. Chirikjian and A. M. Okamura, "Nonholonomic modeling of needle steering," *Int. Journal of Robotic Research,* vol. 25, pp. 509-525, 2006.

[7] D. Glozman and M. Shoham, "Image-Guided Robotic Flexible Needle Steering," in *IEEE Transactions on Robotics, Vol 23, N.03*, 2007.

[8] S. P. DiMaio and S. E. Salcudean, "Needle Steering and Motion Palling in Soft Tissues," 2004.

[9] R. Alterovitz, K. Goldberg and A. Okamura, "Planning for Steerable Bevel-Tip Needle Insertion through 2D Soft Tissue with Obstacles," in *IEEE Intern Conf on Robotics and Automation*, 2005.