Mechanical Characterisation of Lymph Node Tissue and In-Vivo Needle Insertion for EBUS-TBNA

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Abstract. The mechanical behaviour of biological material is an important topic in the field of bioengineering because it is linked to various diagnostic tests and diseases. Endobronchial ultrasound-guided transbronchial needle aspiration (EBUS-TBNA) is used to confirm diagnosis of lung cancer and stage its progression. It relies on insertion of a surgical needle into a lymph node with diagnostic yield (successful sampling of tissue) which is presently highly variable. This study presents experimental tissue measurements relating to EBUS-TBNA and outlines their potential to inform needle design using finite element analysis.

Introduction

A soft material is, generically, one that allows deformation to be viewed or felt without applying excessive force [1], with this being the basis of medical palpation. Some common types of biomaterials include cartilage, brain tissue, most cancers and lymph nodes, which have varying length scales across different organ levels and cellular structures [2] . The focus of this paper is on lymph nodes which are small, kidney-like structures that are part of an adipose tissue capsule [3]. Their pathology is an essential part of lung cancer diagnosis. Endobronchial ultrasound-guided transbronchial needle aspiration (EBUS-TBNA) enables the analysis and staging of different types of cancer by collecting and examining lymph node samples from the mediastinal region. Unfortunately, the accuracy of EBUS-TBNA is not well reported, with the diagnostic yield in the range 60 - 80% [4]. Currently, there is a lack of information about the lymph node's behaviour during needle insertion *in vivo*. The present work aims to gain a better understanding of the hyperelastic response of lymph node tissue in order to experimentally enhance the tissue yield and thus improve diagnosis. This will be done initially via material property input to finite element analysis (FEA) ultimately to improve the design process for EBUS-TBNA needles.

Experimental work

Pig lung lymph nodes were tested with unconfined compression and indentation and needle insertion using a bespoke test rig. 50 lymph nodes were subjected to displacement-controlled relaxation testing through a single indentation/compression cycle at 10% strain followed by a series of cycles at 5, 10, 15, and 20% strains. Needle insertion comprised five series of insertions to a depth of 40 mm using 21 gauge (G) and 22G EBUS-TBNA needles (flat bevel, Vizishot, Olympus, Southend-on-Sea, UK) at four speeds: 13, 9, 3, and 0.5 mm/s. Stress-strain, Fig. 1(a), and force displacement, Fig. 1(b), responses were used to define the hyperelastic material and coefficient of friction parameters as inputs for FEA. Different types of hyperelastic model can be used to describe the mechanical behaviour of soft material with the standard Ogden model used in the present work.

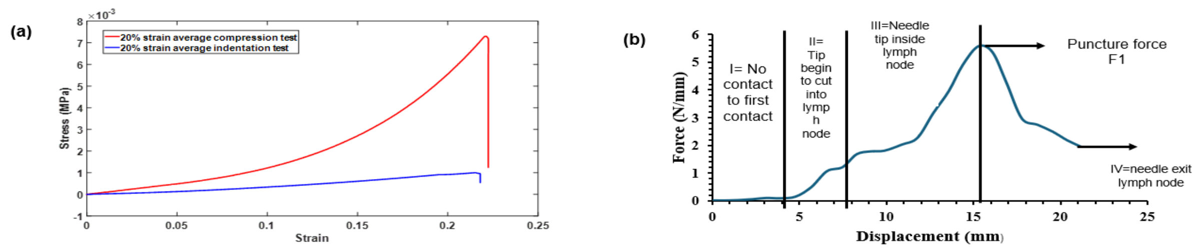

Figure 1: Typical experimental test results, (a): Average compression (red) and indentation (blue) of lymph nodes at 20% strain; (b): 21G EBUS-TBNA needle insertion into lymph nodes at a speed of 13 mm/s.

Simulation

An Abaqus Explicit (Dassault Systemès, Vélizy-Villacoublay, France) FEA model was developed to study the tissue yield of needles, using the properties of the lymph nodes measured experimentally. The model applied the coupled Eulerian-Lagrangian (CEL) method to determine the tissue response during the insertion process. Fig. 2 shows the four phases of the simulation of a complete insertion process: initial contact with the tissue, Fig. 2(a); puncture of the surface, Fig. 2(b); the tip entry into the tissue, Fig. 2(c); and the needle penetration to the full tissue depth of 40 mm, Fig. 2(d). The mechanical properties of the lymph node's hyperelasticity make the needle extend outward both internally and externally and the deformation of the soft tissue inside the tissue is more severe than that outside the needle. The initial findings of the simulation suggest that only a small amount of tissue is pushed into the lumen when using a standard needle. This is assumed to be because of the inefficiency of the second cutting edge. Moreover, as the puncture speed increases, the degree of fitting between the outer wall and the needle puncture gradually decreases, while the stress level increases.

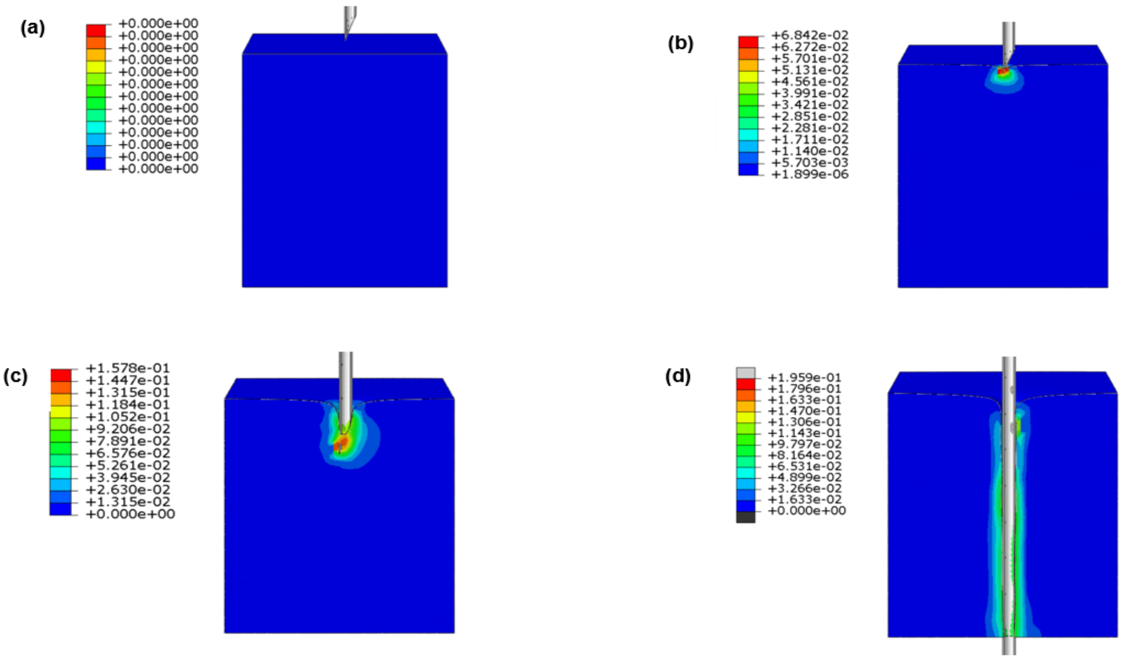

Figure 2: Finite element analysis results of 21G needle insertion into a soft material showing different phase during the process; (a): initial contact with the tissue; (b): puncture of the surface at t = 0.075s and the appearance of stress change area; (c): tip entry into the tissue at t = 0.225s, and (d): needle penetration to the full tissue depth of 40 mm at t = 1.5s.

Conclusion

Through comprehensive material testing, a deeper understanding of the pig lung lymph node mechanical response under load has been achieved. This has allowed development of initial FEA models which are contributing to a thorough understanding of factors affecting tissue yield during EBUS-TBNA. Study of needle tip design will follow.

References

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