Mechanical Characterisation of Soft Materials for EBUS-TBNA

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Abstract

Endobronchial ultrasound-guided transbronchial needle aspiration (EBUS-TBNA) is a biopsy procedure used for sampling lymph node tissue to stage cancers and diagnose granulomatous disease. The failure of this diagnostic procedure through inadequate tissue sample capture by the needle can affect the treatment of patients. In this study, tissue sampling is being explored through mechanical testing and finite element analysis (FEA). The mechanical testing was carried out on phantoms and various soft tissues on a displacement-control basis using the Mach-1 V500C (Biomomentum Inc, Quebec, Canada). The FEA was carried out on a complementary basis using the element deletion-based method to model a bevel-tipped needle interacting with phantom material. The results of this study confirm the nature of soft tissue as being hyperelastic and that Abaqus FEA (Dassault Systemès, Vélizy-Villacoublay, France) is a valuable tool to consider the optimum needle design to maximize the diagnostic yield from the biopsy.

Introduction

Over the past two decades, endobronchial bronchial ultrasound-guided transbronchial needle aspiration (EBUS-TBNA) has transformed how clinicians diagnose lung disease [1]. The process is used to obtain tissue samples for biopsies which are used to diagnose conditions such as lung cancer, sarcoidosis, and tubercular lymphadenopathy and can also identify the spread of the disease from the extra-thoracic region.

During the physical puncture process, it can be difficult to insert the needle into an inter-cartilaginous space due to the anatomy of the lung. It is therefore recommended to take advantage of ultrasound images to visualise the cartilage in the trachea to assist the needle insertion. To target the lymph node, the needle can first be positioned in the fat space of the mediastinum and then inserted into the lymph node by changing its direction. The process of needle movement in the target area is performed back and forth of the order of 10 - 20 times, with the needle's direction modified manually upon each forward motion into the lymph node to allow a larger area to be sampled [2].

Aims of the Work

The quality of the tissue sample is a vital factor that determines the diagnostic yield which, itself, is a measure of how likely it is that the procedure will provide the necessary information to diagnose the disease correctly. The design of the needle tip, the angle at which it is aligned and the motion of the tip inside the lymph node can all affect the quality of the biopsy samples. Moreover, because of the design of the needle, the force acting on its tip during puncture tends to push tissue out of the lumen instead of into it. This can potentially lead to less appropriate or inadequate quantities of tissue being collected.

The aim of the work currently underway is to improve the design of the EBUS-TBNA needle to increase the diagnostic yield of the procedure. The re-design and optimisation of the needle will involve understanding the various characteristics of lymph nodes through mechanical testing and needle insertion experiments. Simulation with finite element analysis (FEA) will also be conducted to replicate the procedure.

Materials and Methods

A lymph node is a small kidney-shaped organ enclosed in a capsule made of adipose tissue. The maximum dimension of a normal lymph node is in the range 1 - 2 cm. If it loses its kidney-shaped form, it is regarded as pathological node. Lymph nodes are considered to comprise soft material with properties that allow easy deformation [3]. Since human tissue can be hard to obtain and test, the work that is presented firstly, involves performing mechanical testing on chicken breast, as a generic, readily available soft tissue; large pickled capers, as a geometric mimic of a lymph node; PVA hydrogel, as a reproducible phantom material which can be tailored to have different properties; and *ex-vivo* porcine lung lymph nodes, as an animal model.

Even though the properties of chicken breast and large pickled capers differ from those of lymph nodes, they can still be used to create mechanical responses of value for needle testing. In the present work, those materials are subjected to unconfined compression testing and indentation testing performed on a displacement-controlled basis using a mechanical tester (Mach-1 V500C, Biomomentum, QC, Canada). Additionally, the Abaqus explicit FEA framework (Dassault Systemès, Vélizy-Villacoublay, France) is used in a three-dimensional model that enables dynamic analysis of needle insertion by applying the element deletion-based technique as a meshing algorithm to explore parameters that are relevant to the study of the needle interaction.

Results and Discussion

The results of both the FEM and mechanical testing are as expected and coincide well with the conclusions drawn by Figueredo et al. [4].The soft materials exhibit a non-linear elastic behaviour, Fig. 1, which is considered to be hyperelastic. Testing on chicken breast showed greater inter-sample variation and this is still under exploration. The element deletion simulation, e.g., Fig. 2, showed that the tissue enters the needle to differing extents according to the tip design.

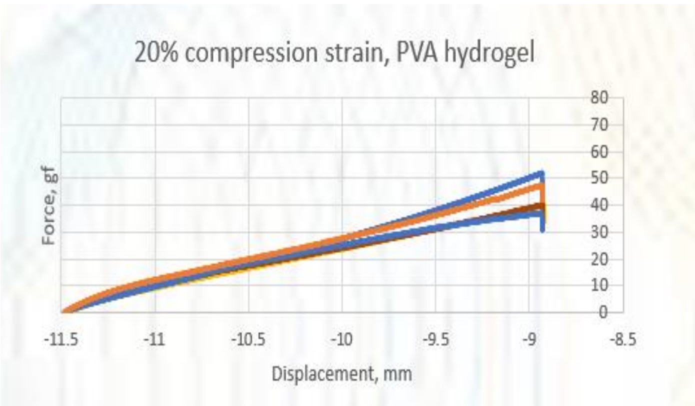

Figure 1:Compression testing response of soft tissue

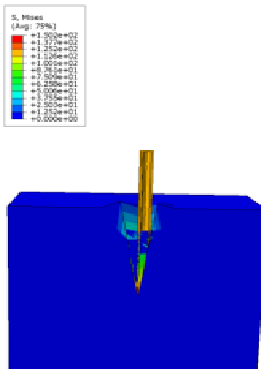

Figure 2: Element-deletion simulation results

Conclusions and Further Work

This work highlights the use of mechanical testing method to characterise soft tissue and a three-dimensional FEA model that enables dynamic analysis of the needle insertion by applying the element deletion method. The results of the study to date conform to the literature and have the potential to serve as a starting point for the development of methodology for the redesign of EBUS-TBNA needle tips.

Future work will focus on the characterisation of human lymph node through indentation testing. The transition between soft tissue layers during needle insertion can lead to a series of event that can cause tissue deformation and rupture, hence through needle insertion experiments, forces acting along the needle and the tip when it come into contact with tissue will be studied. The results will then be explored further with modelling.

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References

[1] D. Feller–Kopman and A. Ernst, ‘Bronchoscopic Needle Aspiration (BNA) and Biopsy: Pro: BNA Requires Routine Use of Real-Time Imaging’, *J. Bronchol. Interv. Pulmonol.*, vol. 8, no. 4, pp. 309–313, 2001.
[2] P. De Leyn *et al.*, ‘Revised ESTS guidelines for preoperative mediastinal lymph node staging for non-small-cell lung cancer’, *Eur. J. Cardiothorac. Surg.*, vol. 45, no. 5, pp. 787–798, 2014.
[3] I. Bujoreanu and V. Gupta, ‘Anatomy, lymph nodes’, 2020.
[4] S. L. Figueredo, W. R. Brugge, and A. H. Slocum, ‘Design of an endoscopic biopsy needle with flexural members’, 2007.