Determination of mechanical properties of soft tissue by rolling indentation, digital image correlation and finite element modelling

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Besides the many advantages minimally invasive surgery offers, the surgeon suffers from the loss of information, visual and mechanical (haptic feedback). The work described in this paper is focused on the re-establishment of the sense of touch using an elastographic measurement approach combined with finite element modelling.

1 Introduction

Minimally invasive surgery has for many applications replaced open surgery, since the amount of tissue, which has to be cut, is reduced to a minimum, resulting in a quicker recovery of the patient connected with reduced post operational stress. But minimally invasive surgery has restricted the working environment of the surgeon due to the loss of two mayor human senses, three dimensional vision and haptic feedback. The haptic feedback (palpation) is an important tool, which helps the surgeon in localizing tumors due to the increased stiffness compared to healthy tissue. Tumorous tissue is 7-14 times stiffer than healthy tissue [1].

Our goal is to re-establish the surgeon's sense of touch in minimally invasive surgery, albeit with an increased sensitivity, increased lateral resolution and the new feature of depth localization, made possible by the information from preoperational data (CT, MRT) and template matching with Finite-Element (FE)-simulation. Furthermore, tissue discrimination (benign vs. malign) will be supported, resulting in reduced amount of functional healthy tissue to be removed. In that manner, important nerves and blood vessels will be preserved.

2 Experiment

Our working principle is based upon the combination of multiscale and multimodal elastographic measurement techniques and a soft tissue applicable FE-Model, which correlates well with the elastographic measurements. From the FE-model a large data bank will be created based on simulating many different scenarios with respect to size, position and shape of the tissue hardening. The results obtained can then be used to solve the under-defined measured data in real time, revealing the location of the tissue hardenings such as tumors, which can then be segmented from the surrounding healthy tissue. A large scale (organ level) elastographic real time measurement device has been developed, as depicted in Fig. 1, which consists of a roll indenter, enabling lateral movement across the sample combined with a feedback loop of controlled force or indentation depth.

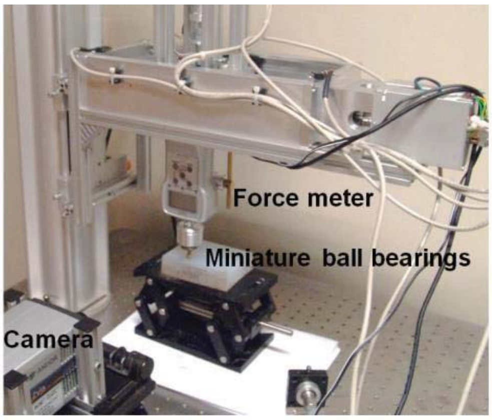

Fig. 1: *Experimental setup for roll-indentation and optical imaging system*

Due to the limitation of available tissue and to test the transfer of information (delivery and processing of data) between the different partners and to create a ground truth, a soft silicon phantom with similar mechanical features as human tissue (kidney) has been developed. Cancerous tissue can be mimicked using a mixture of hard and soft silicon. Color particles have been added to the mixture of the silicon phantom as structural feature for better detection of the displacement. See Figure 2.

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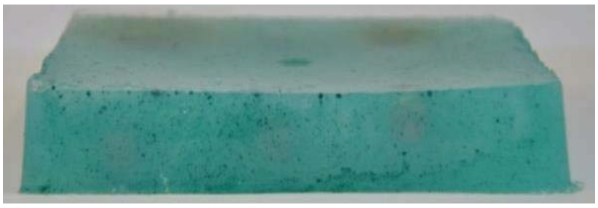

Fig. 2: *Silicon phantom made out of soft silicon ZA00 and Phthalogreen particles for better detection of the displacement*.

The stress-strain curve of the phantom was measured with a macro indenter using a well-defined cylindrical silicon probe, and the result transferred to the partner generating the FE-Model (the Arruda-Boyce model has been employed [2]). The phantom of dimensions 80x100x16mm^3 was then loaded using the roll indenter, see Fig. 1. The indentation depth employed was 3 mm. A deformation vector field could be obtained comparing the location of the particles before and after the application of an external force using localized cross-correlation and moving window function (similar approach as applied to particle imaging velocity PIV [3]). A contour plot of the deformation field is displayed in Fig. 3 central image.

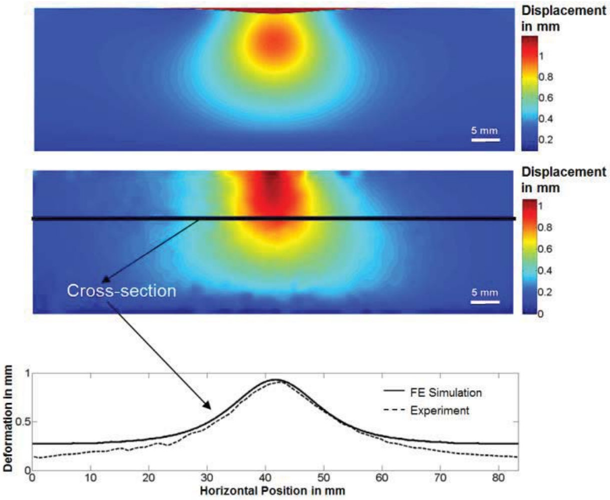

Fig. 3: *Displacement maps obtained, top to bottom: FE-Model, experimental results, cross-section plot (good match at central position).*

The experimental parameters (geometry of phantom, indenter geometry, indentation depth and distance to edge of phantom) have been embedded in the FE-Modell. The deformation maps obtained from the experiment and from the FE-Model have been compared. The cross-section plot shown in Fig. 3 demonstrates that a good match was obtained for the central position (from 15 mm to 40 mm).

3 Discussion and Outlook

For the moment a homogenous silicon phantom has been employed. Future experimental work will be focused on the investigation of a silicon phantom with embedded foreign bodies. Furthermore, other elastographic imaging modalities, imaging scales and excitation sources will be taken into account, which will provide further information about the viscoelastic properties of the sample and hence will improve the measurement accuracy. Having proven the successful applicability of these different measurement tools and having obtained a good agreement with the FE-Model, experiments on biological tissue are planned for future investigations. Miniaturization of the instrument will be another point, which future research focuses upon, leading to an endoscope/laparoscope integrated elastographic measurement system.

4 Support

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