Analysis of Deaeration Deformation in Ex vivo Animal Lung by Laplacian-based Surface Registration

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***Abstract*— This study was performed to analyze deaeration deformation for development of intraoperative guidance of minute lung nodules. We analyzed surface displacement using Laplacian-based surface registration. The registration results were evaluated using reference points manually determined on the lung surface. The registration error was within 1 mm and the magnitude of surface displacement was distributed in an orderly way based on the distance from the pulmonary hilum.**

I. Introduction

Recent advances in imaging techniques have enabled visualization of minute lung nodules in early-stage cancer, and thoracoscopic surgery is often performed as treatment. Although lung nodules are examined using preoperative CT images, the position of the nodules changes during surgery due to deaeration. While respiratory deformation has been widely investigated [1][2], computation models for deaeration deformation have not been developed. This study was performed to analyze deaeration deformation for development of intraoperative guidance of minute lung nodules. This paper reports preliminary results of the analysis on deaeration deformation for ex-vivo animal lung.

II. Method

We extended the Laplacian-based registration algorithm [3] for calculating spatial displacement of lung surfaces. The Laplacian-based registration is described as a least-squares problem for a source and a target mesh model. An evaluation function on positional and discrete Laplacian constraints is defined. To reduce registration error for computing spatial displacement, we introduced additional constraints on the initial shape to the function described in Eq. (1):

$$\arg\min_{V}\left(\sum_{i=1}^{n}\|\delta(L(\boldsymbol{v}'_i)-L(\boldsymbol{v}_i))+(1-\delta)(L(\boldsymbol{v}'_i)-L(\boldsymbol{v}_{0i}))\|^2+\sum_{i=1}^{n}\lambda\|\boldsymbol{p}_i-\boldsymbol{v}_i\|^2\right) \quad (1)$$

where v'_i denotes the modified vertex to be solved, $L(v_i)$ is the discrete Laplacian at vertex v_i, v_{0i} is the vertex of the initial shape, p_i is the positional constraint, V is the set of all vertices, and δ and λ are the experimentally determined weight parameters.

III. Experiments

Ex vivo lung CT images were measured from the left lungs of three Beagle dogs with four internal pressures (12, 9, 6, and 3 cmH_2O) at the Institute of Laboratory Animals, Kyoto University. To simplify the preliminary analysis, we divided the lung region into upper and lower lobes. We used 0.7 for δ and 5.0 for λ after examination of parameter sets.

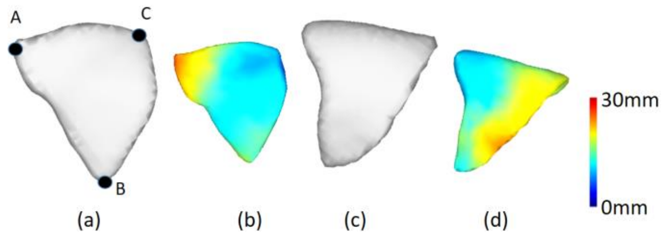

Fig. 1 Visualization of deaeration deformation for an ex-vivo left lung, (a) aerated upper lobe (12 cmH_2O) with reference points, (b) deaerated state (3 cmH_2O) with spatial displacement, (c) aerated lower lobe (12 cmH_2O), and (d) deaerated state (3 cmH_2O).

Fig. 1 shows the aerated shapes (12 cmH_2O) and the deaerated shapes (3 cmH_2O) obtained from Laplacian-based surface registration between the two shapes (12 and 3 cmH_2O). Spatial displacement was visualized using the color map. To evaluate registration error, we selected three reference points (A, B, and C) considered to correspond visually on the lung surface and compared the displacements obtained from surface registration and manual pointing. Table 1 shows the amount of displacements.

Table 1. Amount of displacements obtained from surface registration and manual pointing (mm)

Reference points	Registration	Manual
A	21.3 ± 2.9	21.0 ± 2.4
B	15.0 ± 2.7	14.8 ± 2.0
C	12.7 ± 1.8	12.8 ± 2.1

IV. Conclusion

We introduced additional constraints on the initial shape to the Laplacian-based registration algorithm for calculating spatial displacement of lung surfaces and the registration error was within 1 mm

References

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