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Optimal Design of damper layer in static elastography
静的エラストグラフィにおける緩衝層の最適設計

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1. Introduction

Static elastography is a traditional and simple method, compared with dynamic elastography[1, 2]. If its disadvantage that the estimation of elasticity strongly depends on an applied stress distribution is improved, more appropreate measurement can be done, maintaining its own simple setup of the static elastography. As an effective method that improve a nonuniformity of the applied stress produced with a shape of a transducer head, an insertion of a damper between the tissue and the transducer head is known.

We have been demonstrated the effectiveness of the insertion of the damper through the computer simulations consisted of the structural and acoustic analyses[3]. In this study, the index named "flatness", which is the ratio of the axial strain directly under the edge of the transducer to the strain directly under the center of the transducer at the same depth, is proposed, and the improvement of the flatness is shown by comparison of the elasticity images obtained with and without the damper. In the past study, while the investigations have been done just on the tissue with flat-shaped surface, the effectiveness of the main two parameters when the damper is designed, namely, the Young's modulus and the thickness, have not been investigated.

This study is aimed to find appropriate conditions of the two parameters of the damper, i.e., the Young's modulus and the thickness, through the structural analyse.

2. Design of damper for flat tissue

In our past study, the results of the structural analyses are corresponded to the results of the subsequently performed acoustic analyses in terms of the flatness. Thus, a prediction of increase or decrease of the flatness can be done without the complex acoustic analyses. In this study, the structural analyses are performed in the case of only without the damper and with the dampers with various Young's modulus and thickness, and the optimal values are sought for the two parameters.

A simple 2-dimentional tissue model shown in Figure 1 is used for assessing model. The structural analysis is based on the finite element method (FEM) with a homogeneous tissue model. The tissue is a rectangle with a width of 6 cm and a height of 1 cm, while the width of the transducer is 4 cm. In the case of with the damper, the tissue surface is entirely covered with the damper layer. The tissue is given Young's modulus of 100kPa and a Poisson's ratio of 0.49. The FEM models were built using half models by assuming axial symmetry, and assumed to be attached to a rigid tissue (bone) on the boundary of $y=y_0$. Therefore, a symmetrical boundary condition Ux=0 can be applied to the axis of symmetry of the model, i.e., x=0, and the zero displacement constraints of Ux=0 and Uy=0 are defined at the bottom boundary of the lower soft layer, i.e., $y=y_0$. The other boundaries have no constraint. The tissue was divided into 45 × 20 finite elements.

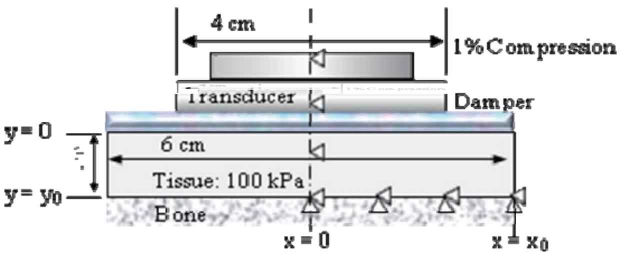

Fig. 1 Simulation model.

2.1 Young's modulus

The damper was given Young's moduli of 10, 50, 100, 500, 1000 and 10^{11}(thus, a flat metal compression board) kPa and a commonly used Poisson's ratio of 0.49. The simulations were executed with a compression stroke of 0.1 mm (1% of the tissue thickness) without and with the dampers. The flatness profiles in cases with and without the dampers are shown in Figure 2. In this case, the flatness, a dimensionless number, is defined as the ratio of the axial strain directly under the edge (x=2 cm) of the transducer ε_e to the strain directly under the center (x=0 cm) of the transducer ε_c at the same depth, i.e.,

$$Flatness = \frac{\varepsilon_e}{\varepsilon_c} \quad (1)$$

Thus, the value of Flatness = 1 is considered as ideal. In Figure 2, the higher Young's modulus of the damper, the lower the uniformity of the strain inside the 1 mm thickness damper.

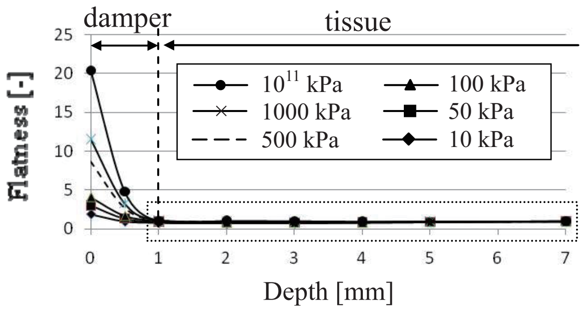

Fig. 2 Flatness distribution in flat tissue. (Parameter: Young's modulus)

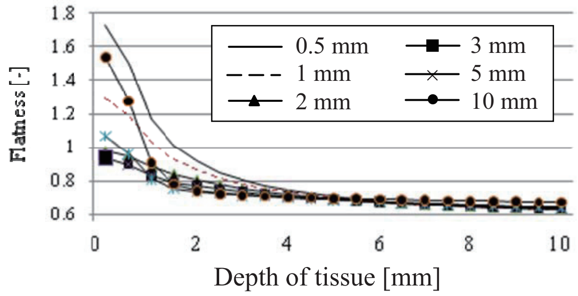

Fig. 4 Flatness distribution in flat tissue. (Parameter: thickness)

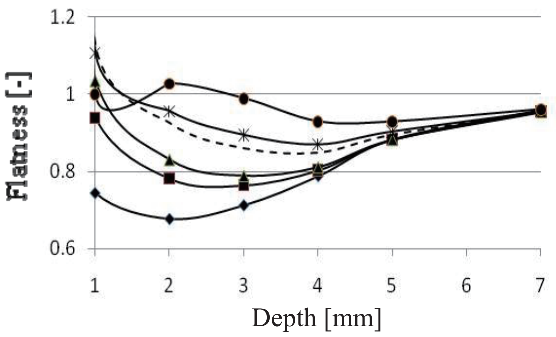

Fig. 3 Partial enlargement of Fig. 2.

The flatness distribution inside the tissue in Figure 2 is partially enlarged in Figure 3. In Figure 3, the higher the Young's modulus of the damper, the more close to flatness=1 inside the tissue. It is considered that a desirable strain distribution is produced with a wide and stiff damper produces.

2.2 Thickness

To search for optimal damper thickness, the Young's modulus of the damper was fixed to 100kPa, and the flatness was obtained by varying the thickness from 0.5 mm to 10 mm. In the all cases of thickness, the flatness was converged to about 0.65 in the deeper region.

However, an obvious difference was found in the shallow region, thus, the low uniformity of the strain was produced in the cases of the thickness of 0.5 mm and 10 mm.
The values close to 1 were obtained in the case of the damper thickness of 2 mm and 3 mm, thus such thickness could be regarded as the optimal value for the tissue model shown in Fig. 1. This knowledge is considered as very useful, if the Young's modulus of object tissue is roughly known.

Conclusions

Performing the structural analysis, the damper for static elastography was optimized on two parameters, namely, the Young's modulus and the thickness. For Young's modulus, the stiffer was better, and for thickness, around 2 or 3 mm was suitable. The optimal combination of these two parameters will be sought in the future work.

References

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