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Optimal Parameter of Damper Layer for Static Elastography
静的エラストグラフィにおける緩衝層の最適パラメータ

Takayuki Sato[1†], Yasuaki Watanabe[1] ([1]Grad. School, Tokyo Met. Univ.)
佐藤 隆幸[1‡], 渡部 泰明 ([1]首都大院)

1. Introduction

The main disadvantage of static elastography is that its estimation of elasticity strongly depends on the applied stress distribution. An effective method of improving the nonuniformity of the stress applied by the shape of a transducer head is to insert a damper between the tissue being analyzed and the transducer head. We previously demonstrated the effectiveness of inserting a damper through computer simulations of structural and acoustic analyses[1].

The present study aims to discover the appropriate conditions for two damper parameters, namely, thickness and the Young's modulus on the tissue with a convex-shaped surface through the structural simulations based on finite element method (FEM). In this paper, the optimal thickness is investigated and discussed as the main parameter of the damper.

2. Method

Human tissue surfaces are curved surfaces with various curvatures. Konofagou et al. have proposed a displacement apodization method for reducing stress nonuniformity and represented the effects of apodization through structural analysis simulations with a flat-surfaced homogeneous tissue model[2]. According to this method, however, a transducer that is optimally designed for a certain tissue surface shape does not perform as an optimal compression board for tissue surfaces of other shapes. In this study, the transmit/receive face of the transducer head was assumed to be a plane, while the shape of the tissue surface was assumed to be convex.

2.1 Model

As Fig. 1 shows, a three-dimensional convex-shaped tissue model was designed for assessing the effectiveness of inserting a damper. The transducer face was a rectangular 1-cm long and 4-cm wide. The convex-shaped tissue consisted of a truncated sphere with a 10-cm radius and 3-cm height, thus 7.1 cm width. The convex tissue had a Young's modulus of 10 kPa and a Poisson's ratio of 0.49 was commonly defined to the tissue and the damper. The transducer and the tissue had a common center axis, and compression was executed. The initial compression stroke along this center axis was defined as 2.15 mm, which is long enough for the entire transducer face to be in contact with the convex tissue surface. And the 1% compression, thus, 0.28 mm, was done. These compressions were regarded as the pre- and post-compressions, and the differential strain distributions for elastography were calculated. As in the case of the flat-surfaced tissue, the damper was assumed to be securely bonded to the tissue surface. The FEM models were built using quater models by assuming axial symmetry, and the tissue was assumed to be attached to a rigid tissue (bone) on the y=0 boundary. Therefore, the symmetrical boundary conditions Ux=0 and Uz=0 can be applied to the axes of symmetry of the model, i.e., x=0, and the zero displacement constraints of Ux=0 and Uy=0 were defined as located at the bottom boundary, i.e., y=0. The other boundaries had no constraints.

2.2 Parameter

The simulations were executed with a compression stroke of 0.3 mm (1% of the tissue thickness) with and without a damper. To assess the effects of damper thickness on convex tissue, the dampers were given a fixed Young's modulus of 10 kPa and various thicknesses, namely, 1, 2, 3, 5, and 10 mm. The flatness, a dimensionless number, is the ratio of the axial edge (x=2 cm) strain ε_e to the center (x=0 cm) strain ε_c at the same depth, i.e.,

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

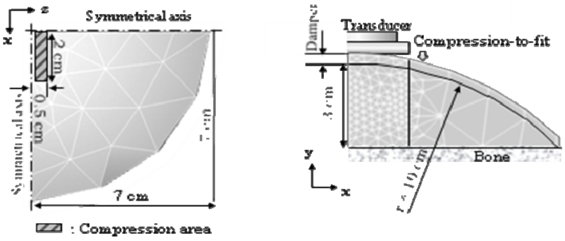
Thus, a flatness value of 1 is considered ideal.

3. Results and Discussions

Figures 2(a) and (b) show the two-dimensional contour mappings and the axial strain plots in the case of without damper. The following two features, which had not been observed in the case of the flat tissue, were found in the results: (1) two minimal peaks in the center strain distributions, (2) plus values of the strain at the shallow depths.

The difference strains between the pre- and post-compression strains and the flatness calculated from the center and edge strains are shown in Fig. 2 (c) and (d), respectively. In these figures, meandering parts were drawn, reflecting the complex strain distributions inside the compressed tissue.

The difference strain distributions obtained



(a) Top view. (b) Side view.

Fig. 1 Simulation model of convex tissue (quarter model).

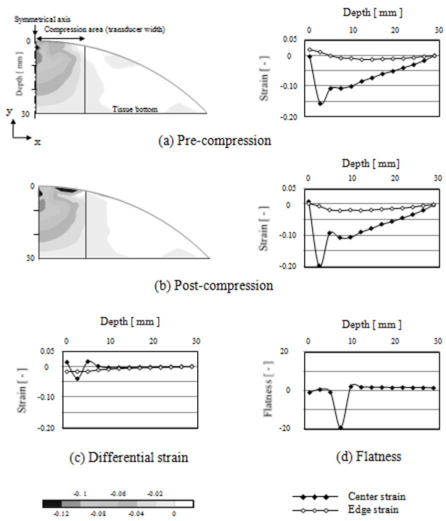


Fig. 2 Results of strain and flatness distributions in convex tissue (without damper).

with the various thicknesses of dampers were separately shown in Fig. 3 (left side). Because both of the damper and the tissue were given the same Young's modulus in these simulations, the effects that the tissue was thickened for the each damper thickness were expected. As the result, the difference strain curves drawn in Fig. 3 were similar to the one which the curve drawn in Fig. 2 (c) was truncated on the shallow region. The sign inversions of the center strain could be found in Fig. 3 (b), (c) and (d), therefore the flatness curves in the case of the convex tissue drawn in Fig. 3 were further form the ideal value than the those in the case of the flat tissue. The very small values of the strain were locally generated among these complex strain distributions, and an extremely large absolute strain in Fig. 3 (c) was obtained, because the index of the flatness was simply defined as the ratio of the

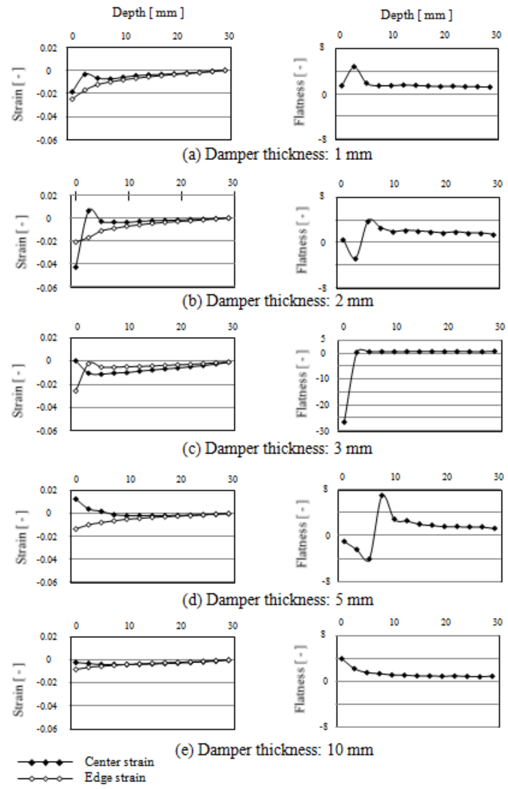


Fig.3 Results of difference strain (left) and flatness (right) distributions in convex tissue (with damper).

edge strain to the center strain. Consequently, a certain trend could not be observed among the flatness curves in Fig. 3, unlikely to the corresponded strain curves with the certain trend of "truncated".

In the case of the convex tissue, as the same as the case of the flat tissue, it was also demonstrated that the thicker the damper, the higher the strain dispersion effect. The lower the flatness value, the more difficult it is to conduct an appropriate elastogram. Thus, it was suggested that direct observations of the flatness and its components, namely, the center and edge strain, were important to assess the damper effect on the tissue with a non-flat surface.

4. References

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