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NUMERICAL EVALUATION OF WEARING PRESSURE AND CLOTH STIFFNESS ON VIBRATION OF HUMAN SKELETAL MUSCLE DURING ATHLETIC MOVEMENT

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Abstract. *In the design of sportswear which is expected to modify the performance of athletes, it is important to clarify the effects of the wear's rigidity and wearing pressure on the vibrations during exercise because they have been considered to reduce the vibrations of muscles. Therefore, in this study, the relationship between the vibration generated in cyclic movement of thigh with cloth and the physical properties of the wearing cloth is discussed by using a simple FE model of thigh [1, 2]. In the analysis, the FE model consisted of three parts of the thigh muscle, the femur, and the wear in the cross section of thigh. The thigh muscle is fixed to the femur but it is in contact with the wear cloth ignoring friction. The condition of the thigh cyclical movement is set assuming the athlete's 100 m run. Numerical analysis is performed under these conditions, and the variations of vibration behavior due to changing values of muscle, wear and pressure are evaluated by mechanical consideration. In the results of this FE analysis, it is quantitatively confirmed that more flexible cloth has the effect of restraining vibration, and also its effect can also be observed by applying wearing pressure to thigh.*

1 INTRODUCTION

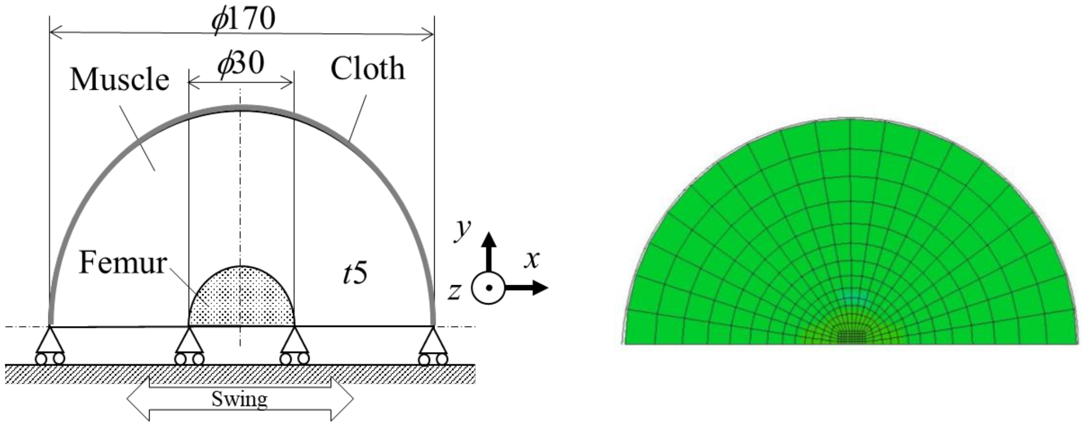
Compression wear is said to have the effect of reducing strain in human body by reducing muscle vibrations, and then it is also said that moderate pressure on the body can improve exercise performance. Here, it was reported that vibration generated in muscle of lower leg can be reduced by compression wear [1]. However, most of these researches are experimentally observed on human being which includes individual differences.

Then, in this study, the simple FE model of the thigh [2, 3] is adopted to analyze the relationship between the vibration generated by the periodic movement of thigh and the physical properties of the clothing precisely.

2 FE MODELING OF HAMSTRING WITH CLOTHE

2.1 Geometry and FE mesh

In this paper, cross section of hamstring is considered to evaluate the deformation behavior of thigh muscle. Figure 1 (a) shows a geometrical model of the hamstring's cross-section with 3 parts of femur, muscle and cloth. Outer diameter of muscle part is 170mm and inner one is 30mm, which is outer diameter of femur part. Half part of the round section is considered to simplify the analysis of defamation behavior by its geometrical symmetricity. The thickness of the section is considered as 5mm with plain strain condition for axis direction *z*. Movement of hamstring is modeled with the cyclic swing of the femur part which is defined by rigid body mechanically. Other parts of muscle and cloth are defined by elastic body for focusing the objective of this study on the mechanical effect of wearing pressure of cloth. Figure 1 (b) shows FE mesh generated in the geometrical parts, and its specification is shown in Table 1. Here, element type of femur and muscle parts is solid with 8 nodes, and cloth part is shell with 4 nods.



(a) Geometrical condition (b) FE mesh

Figure 1: Geomatical condition and FE mesh for numerical evaluation.

Table 1: FEM specification

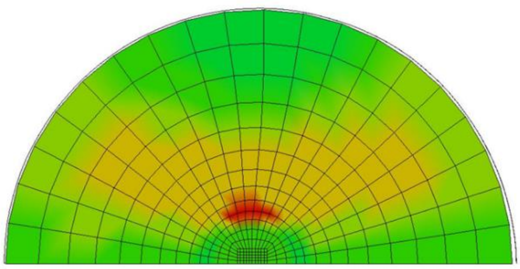
Part	Femur	Muscle	Cloth
Material model	Rigid	Elastic	Elastic
Dimension	Thickness t =5 mm Diameter ϕ =170 mm		
Young's modulus E	—	25 kPa-200 kPa	100kPa-1 MPa
Density	—	1000 kg/m^3	400 kg/m^3
Poisson's ratio ?	—	0.45	0.45
Number of nodes	258	462	122
Number of elements	110	200	60
Solver	Explicit		

Numbers of nodes are 258, 462 and 122, and number of elements are 110, 200 and 60 relatively. FE calculation have done by using LS-Dyna with explicit solver mode.

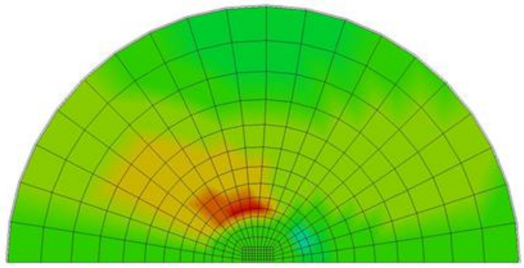
In the mechanical evaluation of wearing cloth, the modulus of muscle and cloth have changed with the pressure control of wearing cloth as shown in Table 1. The frequency of cyclic swing of thigh is 2.5 Hz because this movement of the swing is estimating 100m dash with 50 steps in 10 seconds. The amplitude of thigh swing is 85mm by considering average physique of human.

2.2 Simulated results

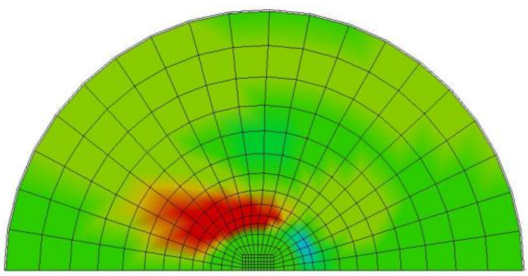
Figure 2 shows the calculated results of FEM, and variation of shear strain due to the pressure caused by cloth shrinkage is compared among figures from (a) to (c). Here, shrinkage for wearing pressure is generated by the function of thermal strain in LS-DYNA with negative coefficient of linear expansion and positive thermal change. Each figure shows the situation at time t = 0.18 s. Here, lift of wearing cloth can be observed in a result of pressure free (p = 0 Pa), but it is not observed in other two pressured condition of p = 20 kPa and 30 kPa. The increase of maximum shear strain due to the increase of wearing pressure can be observed, too.



(a) p = 0 Pa



(b) p = 20 kPa



(c) p = 30 kPa

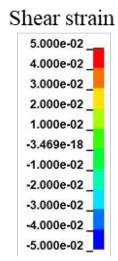
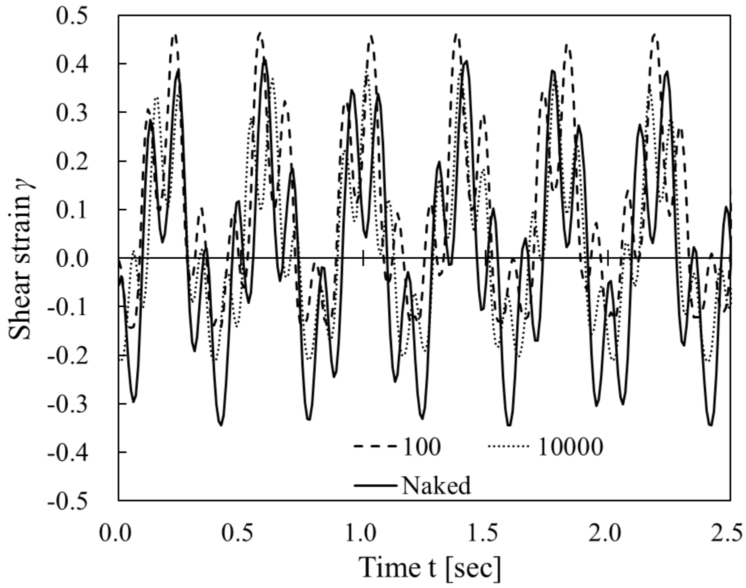
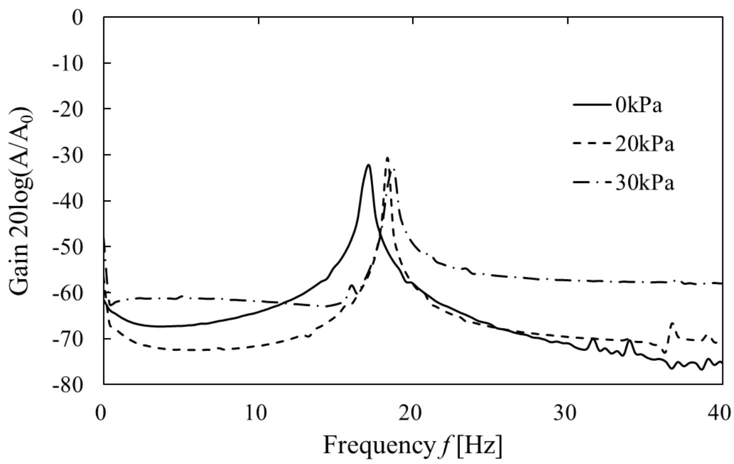


Figure 2: Variation of shear strain distribution induced by wearing pressure.



(a) Variation of strain fluctuation due to cloth rigidity



(b) Frequency analysis

Figure 3: Strain fluctuation and analyzed frequency in pressure p = 50 kPa.

From the results of FEM shown in Figure 2, the fluctuation of strain is derived as shown Figure 3 (a) and result of frequency analysis is shown in Figure 3 (b). In the results of strain fluctuation, the increase of maximum shear strain and due to the increase of cloth rigidity is observed with decrease of minimum shear strain. In the frequency analysis, peak shift to higher range due to increase of the pressure is observed with gain growth in high frequency region. As the result of this Figure 3, not only the amount of shear strain but also the shift of frequency mode are observed by wearing the compression wear.

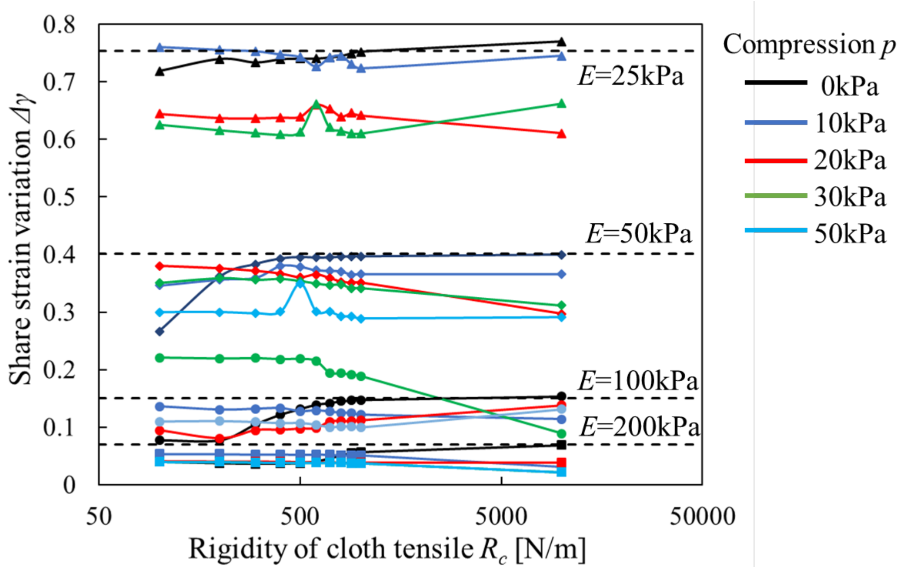


Figure 4: Analysis of shear strain variation

In order to summarize the results of numerical analysis, variation of strain amplitude, which is the difference between maximum and minimum shear strain, is analyzed by changing muscles elasticity E, cloth rigidity Rc, and wearing pressure p. Here, the variation of shear strain $\Delta\gamma$ can be decreased by the increase of muscles elasticity E, and increase of pressure p can decrease the variation of shear strain $\Delta\gamma$. This decrease by the increase of muscles elasticity E can be explained by fundamental Hooke's law or the change of stress wave by pressure p.

3 CONCLUSIONS

- In order to investigate the effect of wearing pressure, a simple cross section model has been developed for the analysis by finite element method, and then the analysis of shear strain in simulated results shows the complexity of deformation behavior change in moving process of muscle.
- The increase of maximum strain can be observed with the decrease of shear strain variation by the increase of wearing pressure.

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