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特発性側弯症の発症メカニズムの検討

Study on pathogenic mechanism of idiopathic scoliosis

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1. Introduction

The cause of idiopathic scoliosis is still unknown. The features of idiopathic scoliosis comprise spinal irregularity with lateral curvatures together with rotation without any marked abnormality of the vertebrae or associated musculoskeletal condition. Since almost all cases of the disorder appear during adolescence, particularity during growth spurts, growth has been recognized as a key factor for pathogenesis of idiopathic scoliosis.

With respect to the pathogenesis of idiopathic scoliosis, a large number of hypotheses and physical models have been presented. From the point of view in mechanics, we can classify these concepts into two types: that growth itself is asymmetrical; or that buckling is induced by symmetrical growth of the vertebral bodies, which we call the buckling hypothesis(1).

For the buckling hypothesis, Dickson et al.(2) presented an important observation on flattening of the thoracic spine during growth spurt. They identified the trigger of rotational instability as median plane asymmetry, which means flattening or reversal of normal thoracic kyphosis at the apex of the curvature, and declared this instability as a buckling phenomenon.

Based on Dickson's hypothesis, the authors analyzed the buckling phenomenon induced by the growth of vertebral bodies using finite-element models of spine by the linear buckling theory. Using a commercial program (MSC.Nastran 7.0), we obtained the fourth and sixth buckling modes which are similar to the clinical single and double-major curves, respectively(1).

However, in case using a program based on the nonlinear buckling theory, clear buckling modes similar to the clinical modes could not be obtained(3). After this investigation, we reanalyzed the linear buckling modes using another commercial program. Then, we found that there is a program by which any buckling phenomena is not obtained.

From the dependency of programs, we had the doubt whether the buckling phenomenon exists or not. In the present paper, returning to the starting point, we confirmed the existence of the buckling phenomenon using rather simple models, and made clear the region in which the phenomena occur.

2. Method

Figure 1 shows the shapes of the finite-element models used in the present study. All of the models have the same height $h = 500$ [mm] and depth $d = 50$ [mm]. Front width w_{F}, back width w_{B} and depth of growth domain g are chosen as variables. We use 8 [MPa] and 0.3 as Young's modulus and Poisson's ratio, respectively. Those values are determined such that the side bending deformations of the finite element models have the same order with the experimental result by Lucas et al.(4). The second-order tetra element is used. The number of elements is about 6,500.

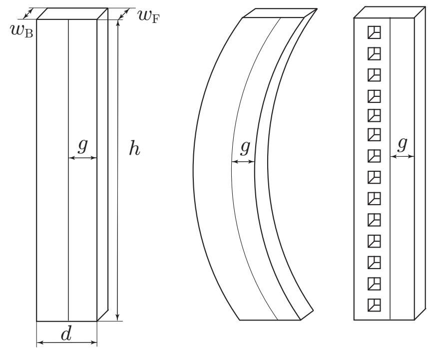
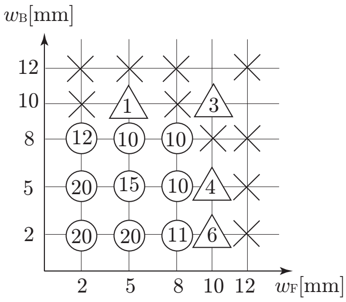


Fig. 1 Models

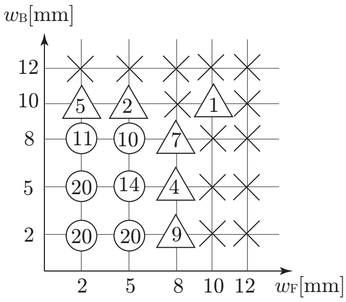
We assume that only the bottom plane corresponding to the sacrum is fixed as the base position of deformation. The growth of the vertebral bodies is modeled by the thermal expansion in thermal elastic problem. 0.1 is used as the value of the growth, which has unit of strain [-], in the growth domain of $(0, g) \times h \times w(g)$, where $w(g) = w_{\mathrm{F}} + (w_{\mathrm{B}} - w_{\mathrm{F}})g/d$. A finite element solver RADIOSS 11.0 (Altair Engineering, Inc.) is used to solve the thermal elastic problem and the linear buckling problem based on the result of the thermal elastic problem.

3. Results of buckling analyses

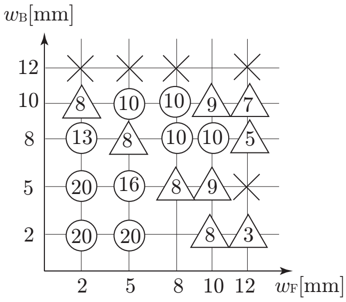
Figure 2 shows the results of the existence maps of the buckling modes in w_{F}–w_{B} space for Model 1 to Model 3, respectively, when only the nodes on the front surface are assigned to growth, i.e. $g = 1.25$ [mm], which is the half of the mesh size. The numbers in circles mean the number of buckling modes more than 10. The numbers in triangles imply the number of buckling modes at the range from 1 to 10. The cross means no buckling phenomenon with this parameters of $(w_{\mathrm{F}}, w_{\mathrm{B}})$. From those results, $(w_{\mathrm{F}}, w_{\mathrm{B}}) = (8, 8)$ [mm]^2 can be considered as the parameters in order that the buckling modes occur stably. The buckling factors of the first modes for Model 1 to Model 3 at $(w_{\mathrm{F}}, w_{\mathrm{B}}) = (8, 8)$ [mm]^2 are 41.0, 41.7 and 42.6, respectively. Figure 3 shows the dependency of depth g on buckling factors for Model 1 and Model 2. Figure 4 shows the buckling mode shapes for Model 1 at $(w_{\mathrm{F}}, w_{\mathrm{B}}) = (8, 8)$ [mm]^2 and $g = 10$ [mm].



(a) Model 1



(b) Model 2



(c) Model 3

Fig. 2 Existence maps of the buckling modes in w_F–w_B space

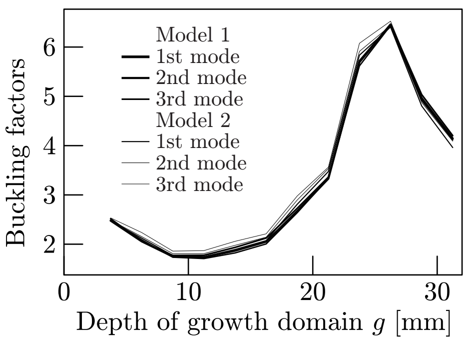
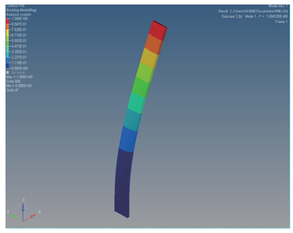


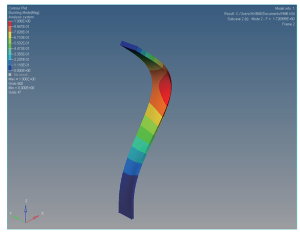
Fig. 3 Dependency of depth g of growth domain on buckling factors for Model 1 and Model 2

4. Discussion

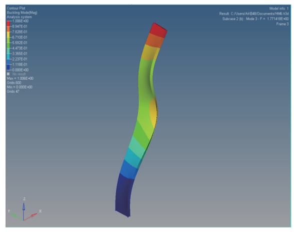
From the results of Fig. 2, it is confirmed that there are boundaries between the domain in which bucklings occur and the domain in which any buckling does not occur. Moreover, that the area of the domain in which bucklings occur for Model 1 is larger than that for Model 2 supports Dickson's hypothesis, namely flattening increases possibility falling into a buckling phenomenon. That the area in which bucklings occur for Model 3 is larger than that for Mode 1 means that the structure of spine which has caves in the rear part of vertebrae makes buckling phenomenon easier to cause.



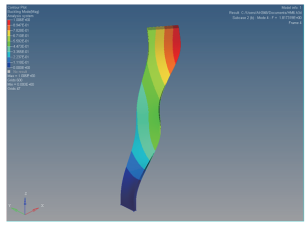
(a) 1st mode



(b) 2nd mode



(a) 3rd mode



(b) 4th mode

Fig. 4 Buckling mode shapes for Model 1 at $(w_F, w_B) = (8, 8)$ $[\text{mm}]^2$ and $g = 10$ [mm]

5. Conclusion

This paper investigated buckling phenomena of the simplified spine models induced by the growth of vertebral bodies using finite-element method. Based on the results, we confirmed the existence of the buckling phenomena, and made clear the region of geometrical parameters in which the buckling occur. These results support the hypothesis of Dickson. Analyses using fine spine model considering geometrical nonlinearity remain for future work.

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