A Study on Structural Optimality of Cervical Spine of Giraffe

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Head and neck of giraffe over 2m long and weighs 150kg. Such long and heavy neck of giraffe is subjected to large moment and force. Giraffe can swing the neck flexibly in spite of the severe mechanical condition. So, mechanical adaptation is expected on musculoskeletal structure of giraffe’s neck. Several anatomical studies of musculoskeletal system of giraffe’s neck have been reported, however, there was no biomechanical study. Purpose of this study is to evaluate the mechanical strength of giraffe’s neck and to consider its mechanical optimality.

We created the finite-element model based on CT images taken from the skeletal specimen of giraffe owned by the Osaka Museum of Natural History. The cervical spine model was composed of skull, all cervical vertebrae, 1st and 2nd thoracic vertebra, vertebral disks and nuchal ligaments. Inhomogeneous material properties of vertebrae were given due to bone mass density obtained from CT value. Material properties of vertebral disks and nuchal ligaments were assumed by using other animal data of past literature. From horizontally extending to lowers the head postures were considered. Alignment of the vertebrae in the model was determined by referring anatomical charts of giraffe and other mammals. Gravity loads correspond to the mass of head and each vertebra levels were applied. Mass of head and neck were assumed as 20Kg and 70Kg. The mass of neck was divided into each vertebra levels in according to their length. Posterior end of the 2nd thoracic vertebra (T2) was fixed, and the ligament was fixed at insertion point of spinous process of T2. FE analyses were performed for two cases in order to ensure influence of bone inhomogeneity, in the horizontally extending posture. One was homogeneous bone case (case 1) and the other was inhomogeneous bone case (case 2). In case 1, average of bone densities were given separately for cortical shell and solid of the vertebrae. Maximum tensile principal stresses of case 2 are totally lower than case 1 especially for C5 and C7. Belt-like high-density area at central part of C5 is effective to reduce large tensile principal stress occurred at anterior side, because nuchal ligament force is supported by the high-density area.

Furthermore, we considered minimum volume design problem of hourglass-shaped column constrained bone stress and intervertebral joint stress under compression load and bending moment by using beam theory, to explain hourglass shape of the cervical vertebrae. Center diameter is smaller than end diameter on the minimum volume design, because bone strength is larger than strength of intervertebral disc and both stress constrain is active. We measured cross sectional ratio of center and end in C4 vertebra, and compared it to the cross sectional ratio obtained by solving the minimum volume design problem. The measurement value corresponded with the theoretical value when compression load was dominant. It is suggested that shape of cervical vertebrae of giraffe is mechanical optimal.