INTRODUCTION
Breakage of the screws which may cause non-union or collapse of vertebral structures has been a complication of the pedicle screw fixation at a rate of 3-7% [1-2]. Recently, flexible rods have been used for dynamic stabilization to avoid complications such as adjacent segment degeneration due to excessive stiffness of the spinal fusion by allowing intersegmental motion at the surgical level [3]. Thus, it is necessary to investigate the influence of the flexible rods on the breakage risk in the pedicle screw fixation. However, there have been few studies of the breakage risk in the dynamic stabilization system using flexible rods. In this study, the breakage risk in the pedicle screw fixation was analyzed using finite element method for the rods with various flexibilities.

METHODS
A finite element model of the lumbar spine (L1-S1) was developed based on computed tomography (CT) scanning of a 1 mm slice from L1 to S1 (sacrum) performed on a male subject with a height of 175 cm. The finite element model consisted of six vertebrae, five intervertebral discs, and seven kinds of ligaments. The finite element models of a pedicle screw, a conventional rod, and a flexible rod in the BioFlex System (Bio-Spine Corp., Seoul, Korea) were also constructed. The conventional rod is a cylindrical straight rod of titanium with 6 mm diameter, and the flexible rod of nitinol, a shape memory alloy of nickel and titanium, has a helical spring shape of two turns with a 4 mm diameter. In addition, helical spring rods with 2 mm and 3 mm diameters were also developed to investigate the effect of more flexible rod on breakage. Finally, four models of a posterior one-level spinal fixation at L4-L5 using 1) straight rods, 2) helical spring rods with a normal diameter (4 mm spring rods), 3) the helical spring rods with a 3 mm of diameter (3 mm spring rods), and 4) the helical spring rods with a 2 mm of diameter (2 mm spring rods) were developed (Fig. 1). The lower part of the sacrum (S1) was fixed and then, 5 Nm of flexion, extension, lateral bending, and torsion moments were applied superior to L1 with 400 N of compressive load along the follower load path. The von-Mises stresses, which were chosen as the breakage risk parameter, in the screws and the rods were predicted using the finite element analysis (ABAQUS™, ABAQUS Inc., Providence, RI, USA).

RESULTS
The von-Mises stresses were concentrated on the neck region in the pedicle screw and the middle region in the rod, regardless of the fixation system as well as the loading condition (Fig. 2). The average values of the maximum stresses in the four neck regions of the left-upper, left-lower, right-upper, and right-lower pedicle screws were reduced regardless of the loading conditions while the fixation system was more flexible (Fig. 3). The ratios of the maximum stress in the rods to the yield stress in order to consider the difference of materials, the titanium and the nitinol, were much high in the 2 mm spring rods: 15.7%, 14.2%, 15.8%, and 51.8% in flexion, 9.1%, 13.1%, 15.4%, and 46.1% in extension, 12.2%, 17.9%, 21.0%, and 41.2% in lateral bending, and 13.2%, 18.7%, 20.4%, and 49.8% in torsion, for the straight, the 4 mm spring, the 3 mm spring, and the 2 mm spring rods respectively.

REFERENCES

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