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Short communication

Investigation of optimal follower load path generated by trunk muscle coordination

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ABSTRACT

It has been reported that the center of rotation of each vertebral body is located posterior to the vertebral body center. Moreover, it has been suggested that an optimized follower load (FL) acts posterior to the vertebral body center. However, the optimal position of the FL with respect to typical biomechanical characteristics regarding spinal stabilization, such as joint compressive force, shear force, joint moment, and muscle stress, has not been studied. A variation in the center of rotation of each vertebra was formulated in a three-dimensional finite element model of the lumbar spine with 117 pairs of trunk muscles. Then, the optimal translation of the FL path connecting the centers of rotations was estimated by solving the optimization problem that was to simultaneously minimize the compressive forces, the shear forces, and the joint moments or to minimize the cubic muscle stresses. An upright neutral standing position and a standing position with 200 N in both hands were considered. The FL path moved posterior, regardless of the optimization criteria and loading conditions. The FL path moved 5.0 and 7.8 mm posterior in upright standing and 4.1 mm and 7.0 mm posterior in standing with 200 N in hands for each optimization scheme. In addition, it was presented that the optimal FL path may have advantages in comparison to the body center FL path. The present techniques may be important in understanding the spine stabilization function of the trunk muscles.

1. Introduction

The follower load (FL) is the concept that compressive loads are carried along a FL path passing through the center of rotation of each vertebra approximating the curve of the lumbar spine (Patwardhan et al., 1999; Shirazi-Adl and Parnianpour, 2000). It has been reported that the load carrying capacity of the spine is significantly increased under the FL by experiments applying the FL to the spine through cable guides attached to the vertebral body center (Patwardhan et al., 1999, 2003). In addition, it has been shown that the FL could be generated *in vivo* by the trunk muscles using a finite element model of the lumbar spine with a large number of trunk muscles (Kim and Kim, 2008; Kim et al., 2007, 2010a; Patwardhan et al., 2001). Currently, the FL is assumed to be the upper body weight and the resultant force by the *in vivo* trunk muscles for the loading condition in experimental and computational studies (Rohlmann et al., 2009a,b; Wilke et al., 2003).

It has been reported that the center of rotation of each vertebral body is located posterior to the vertebral body center (Pearcy and Bogduk, 1988). Moreover, it has been suggested that an optimized FL acts posterior to the vertebral body center. Han et al. (in press) reported that the follower forces were minimal when the FL path was assumed to be 7 mm posterior to the path connecting vertebral body centers. Dreischarf et al. (2010) showed that the optimal position of the FL path to minimize the intervertebral rotation at each level was about 2 mm posterior to the path connecting the vertebral body centers. However, the optimal position of the FL path might be affected by the optimization criteria. The optimal position of the FL path with respect to typical biomechanical characteristics regarding spinal stabilization, such as joint compressive force, shear force, joint moment, and muscle stress, has not been studied. In this study, a variation in the center of rotation of each vertebra was formulated in a three-dimensional finite element model of the lumbar spine to consider trunk muscle coordination. Then, the optimal FL path connecting the centers of rotations was investigated with respect to biomechanical characteristics related to the spine stabilization.

2. Materials and methods

We used a three-dimensional finite element model of the lumbar spine from T12 to S1 in an upright standing posture developed by Kim and Kim (2008) and Kim et al.

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