Development of a dynamic model of a cyclist's lumbar spine

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Abstract. A dynamic model of a bicyclist's lumbar spine was developed to evaluate the linear and angular variation of intervertebral distance in sagittal plane. Ten degrees of freedom biomechanical model of the spine was solved numerically. Larger loads acting on a cyclist spine were predicted mostly while sitting in a sport position in comparison with recreation or middle sitting. The load on the lumbar spine region is influenced by cycle's tire pressure, road bumps and riding velocity.

Keywords: spine, biomechanical model, dynamics, bicycling, accelerometry, force.

Introduction

Spine diseases and pain are a common social problem in Lithuania and other world countries. Mostly problem occur in the lumbar spine and are summarized as low back pain (LBP) syndrome [1, 2]. LBP and other spinal diseases are a common problem in cyclists, because they have to orient the spine in parallel with the horizontal plane for reaching the best aerodynamic position. Due to back overload about 30% of cyclists after race have to be consulted by a physician. Often the corresponding diagnosis is made as "undefined chronic pain" as a result of lack of spine biomechanics' investigations [3]. Severe back pain most often arises from physical disruption of spinal structures like intervertebral discs, apophyseal joints and sacroiliac joints [4]. Prolonged flexed posture during cycling influences muscle fatigue and increased mechanical strain of the lumbar spine [5, 6]. Also riding surface unevenness can influence overall comfort during bicycle rides [7]. The aim of this study is to develop a dynamic model of cyclist's lumbar region of the spine and evaluate the intervertebral distance variation which depends on wheeling regime and cyclist sitting position.

Materials and methods

Assuming that the main loading of the lumbar spine comes from the contact between bicycle seat and riders buttock during the riding on different surfaces and with different velocity, experimental measurements of the accelerations acting on the cyclist were performed. 2-axial accelerometer ADXL320 was mounted on the seat-post of the bicycle so that sensitive axes were coincident with driving direction and vertical axis. By varying tire pressure and speed while driving on two different road surfaces various spine loading scenarios were evaluated. In order to investigate intervertebral linear and angular displacements a ten degrees of freedom dynamical model consisting of 5 lumbar region spine vertebrae was developed (Fig. 1) and system of 10 second order differential equations of motion (1) (for simplicity only two equations for 1st body are shown) were deduced using Lagrange energy method.

$$\begin{cases} m_1\ddot{x}_1+\dot{x}_1\left(c_{121}+c_{221}+c_{12}+c_{11}\right)-\dot{x}_2\left(c_{121}+c_{221}\right)-\dot{\varphi}_1\left(c_{121}a+c_{11}a-c_{12}b-c_{221}b\right)-\dot{\varphi}_2\left(c_{221}b-c_{221}a\right)+ \\ +x_1\left(k_{121}+k_{11}+k_{221}+k_{12}\right)-x_2\left(k_{121}+k_{221}\right)-\varphi_1\left(k_{121}a+k_{11}a-k_{121}b-k_{12}b\right)+\varphi_2\left(k_{121}a-k_{221}b\right)=F_{t1}+F_{t2}, \\ J_1\ddot{\varphi}_1-\dot{x}_1\left(c_{121}a+c_{221}b+c_{11}a+c_{12}b\right)+\dot{x}_2\left(c_{121}a-c_{221}b\right)+\dot{\varphi}_1\left(c_{121}a^2+c_{11}a^2+c_{221}b^2+c_{12}b^2\right)- \\ -\dot{\varphi}_2\left(c_{121}a^2+c_{221}b^2\right)-x_1\left(k_{121}a+k_{11}a-k_{221}b-k_{12}b\right)+x_2\left(k_{121}a-k_{221}b\right)+\varphi_1\left(k_{121}a^2+k_{11}a^2+k_{221}b^2+k_{12}b^2\right)- \\ -\varphi_2\left(k_{121}a^2+k_{221}b^2\right)=M_1-F_{t1}a+F_{t2}b, \end{cases} \quad (1)$$

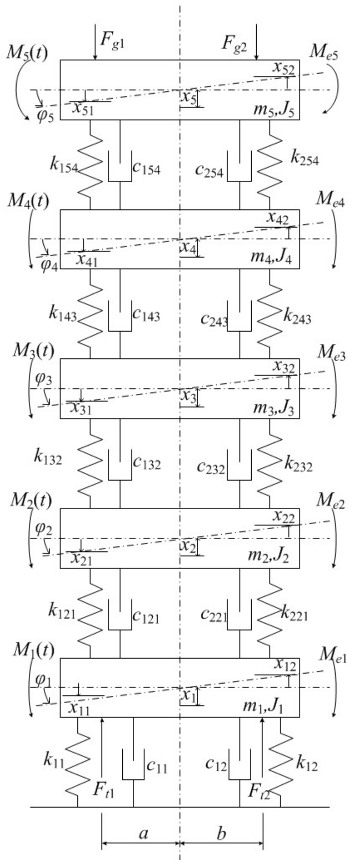

Fig. 1. Dynamic model of cyclist's spine lumbar region: J_i – moments of inertia, x_i – mass displacements, x_{i1}, x_{i2} – mass position variation because of rotation

Intervertebral discs stiffness, damping constants [8] and vertebra's inertial characteristics [9] were chosen from scientific literature. The sitting position of the cyclist affects the load on the lumbar spine. Therefore three spinal inclination angles representing three sitting postures (sport, middle, recreational) were chosen. The external moment M_{ei} due to the sitting position was used to simulate the loading in the biomechanical model.

To solve the equations of motion a variable order method based on numerical differentiation formulas, which is designed specifically to deal with stiff differential systems of equations, was used. This method helped to determine parameters of the lumbar spine, i.e. linear and angular displacements during each wheeling regime and sitting position at cycling. The largest linear and angular displacements were found between vertebrae L4-L5. This can be explained by the increase of a moment arm and concentration of a mass at this place.

Results and Conclusions

At 30 km/h speed and 3.5 bar tire pressure cyclist lumbar spine the model predicted maximum loads of approximately 3.2 kN parallel to the *x* axis during riding on asphalt and approximately 4 kN on a gravel road. During riding external frequency distributes in rage from 10 Hz to 40 Hz. The largest loads were determined for a sitting position. Maximum vertebrae angular and linear variation values at riding regime with 1.5 bar tires pressure and at 10 km/h speed are 0.46˚ and 0.46 mm. Maximum vertebrae rotation and linear variation values at riding regime with 3.5 bar tires pressure and at 30 km/h speed are 3,9˚ and 1.23 mm. The biggest variation of rotation in sagittal plane between two nearest lumbar spine is about 1˚. Because of this displacement frontal part of last mentioned disc is compressed with 530 N more and dorsal disc part as many less.

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