ON MODELLING SPINE CURVATURE DEPENDENT ON MUSCULAR AND EXTERNAL FORCES IN MULTIBODY DYNAMICS SYSTEM

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SUMMARY

This paper presents a computational approach for investigating effect of muscular and external forces on curvature of the lumbar spine. Multibody dynamics system is used to compute the lumbar spine curvature using a force-dependent kinematics facility, e.g. this method allows releasing some degrees of freedom in order to be computed based on the current load configuration.

INTRODUCTION

The shape of the curved lumbar spine and associated muscle forces can be very descriptive and helpful in understanding of different spine curvature disorders, low back pain and even some pathological scenarios. Furthermore, this knowledge can be used to develop rehabilitation strategies or to state new physiotherapeutic recommendations. Alternatively it can be utilized for the design of new medical devices, e.g. spine fusion or intervertebral disc replacement elements.

However, *in vivo* measurement of such forces is a difficult and often unethical task. A good computational model would certainly be of great help for answering such research questions. Several existing models suggest using a predefined shape of the spine based on the thoracopelvic angle and kinematic rhythm [1], or a fitted B-spline into recorded vertebral positions [2], etc. However, these assumptions are too simplistic and obviously do not describe interpatient and muscle-induced variability.

This paper proposes a technique of modelling lumbar spine curvature caused by an immediate force configuration in the body, e.g. the lumbar spine adjusts its shape for a particular simulation step based on the muscular and external forces.

METHODS

This work has been done in the Anybody Modelling System™ (AMS) (Anybody Technology A/S, Aalborg, Denmark). AMS is a multibody dynamics system for computation of muscular load configuration from an imposed motion of a human body or a part of it. A detailed generic human body model including a lumbar spine unit [1] was used from the Anybody Managed Model Repository (version 1.3). For this study muscle definitions were inherited from the original model and only passive elements were introduced. In order to improve the generic human model several modifications were implemented (Figure 1). First, the ligaments of the lumbar spine were added. Anterior and posterior longitudinal groups of ligaments were added to the lumbar spine spanning from T12 down to the sacrum. Anatomical positions were chosen according to the model's geometry and corresponding locations taken from anatomical handbooks. Similarly interspinous, supraspinous, intertransverse ligaments and ligamenta flava were added. Material properties were adopted from available literature [3,4]. Furthermore, rotational stiffness values (originally adopted from [5]) assigned to model intervertebral discs as spherical joints positioned in the instant centres of rotation were reduced considering the ligament forces and their effect on the lumbar spine kinematics. Aforementioned modifications were chosen as they seem to perform in a good agreement with available literature, both experimental and computational studies, on different scales [6].

Force-dependent kinematics is a new facility available in the AMS starting from a version 5.0. It allows incorporating unconstrained degrees of freedom of the modelled joint positions into an inverse dynamics analysis, where these joints will be computed using current muscular and external forces. In this study the force-dependent kinematics approach was applied to the lumbar spine: all spherical joints (T12-S1) were set to have a force-dependent constraint type.

Several scenarios were investigated in order to assess validity of the method and its benefits as opposed to the previous model. Original and improved models were subjected to a motion starting from a flexion of 15 degrees to an extension of 20 degrees. This motion was driven by the thoracopelvic angle. Furthermore, elastic spring-like elements of different stiffness were positioned between the pedicles of L4 and L5 vertebrae to reduce motion of this spinal motion segment and analyse how this will affect the intervertebral kinematics of the lumbar spine. Two different stiffness values were investigated.

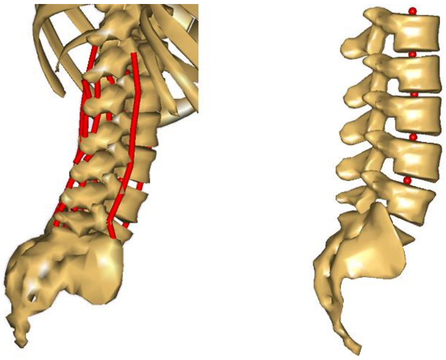

Figure 1: Spine model modifications: (left) lumbar spine ligaments - red segments; (right) spherical joints in instant rotation centres were assigned reduced rotational stiffness values as opposed to Schimdt *et al.*

Finally, computed dynamic lumbar spine curvature and its pattern have to be compared against experimental data recorded for a set of people who underwent voluntarily flexion/extension activities.

RESULTS AND DISCUSSION

The implemented improvements of the lumbar spine model change the distribution of the intervertebral angles in a curved spine – these angles change in a non-proportional manner as opposed to the original model (Figure 2 a,b). Addition of the elastic elements, which may be considered as motion reduction devices, or modification of stiffness values of the passive elements lead to redistribution of intervertebral angles, where other joints compensated for these changes (Figure 2 c,d).

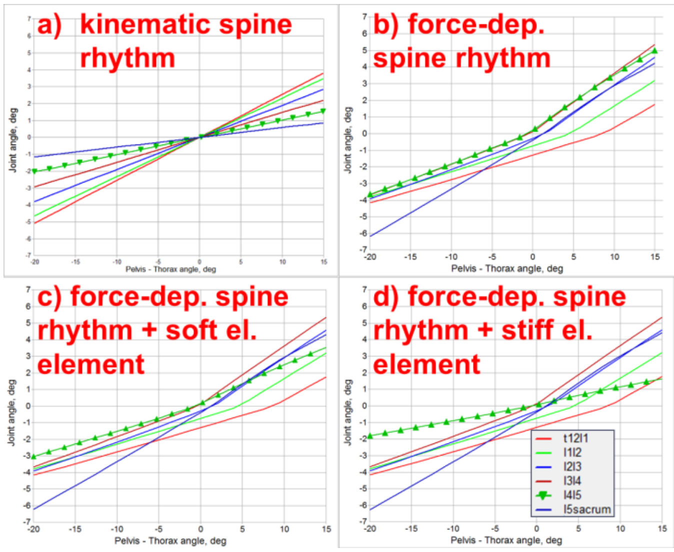

Figure 2: Distribution of intervertebral angles of the lumbar spine for flexion/extension motion (saggital plane): (a) original model – linearly distributed intervertebral (IV) joint angles; (b) improved model – nonlinear distribution of IV joint angles; (c) with an elastic element at L4L5 spinal motion segment (5N/mm) – L4L5 angle is reduced, but compensated by other joint angles; and (d) with an elastic element at L4L5 spinal motion segment (25N/mm) – effect of (c) is enhanced.

Comparison of the results to the experimental data is still in progress. It is anticipated that the exact picture of the angle distribution do not necessary match, however, there is a similar trend on how the intervertebral joint angles are attributed for a particular value of the thoracopelvic angle.

Preliminary results indicate that this approach to model the lumbar spine can facilitate patient-specific modelling of the lumbar spine, i.e. it is possible to modify lumbar spine ligament properties and see the effect on the posture. It also enables a facility to include external objects into such model (a fixation device, an artificial intervertebral disc, etc.) and see their effect on the posture and biomechanics of the spine. Furthermore, it is expected, that by introducing these improvements it becomes possible to see the effect of facet joints and contact forces on the kinematics of the lumbar spine, however, in order to assess that further a robust facet joint model is required.

CONCLUSIONS

This model allowed eliminating a prescribed kinematic rhythm for the lumbar spine and enabled integrating patient-specific parameters such as lumbar spine ligament strengths. It showed an improved performance compared to the original model, however, a further investigation is required to draw final conclusions on how accurate the model is. Despite of this necessity it is clear that the suggested approach is beneficial for modeling spine kinematics and can be a good starting point for a multibody dynamics-based lumbar spine model.

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