A validated thoraco-lumbar spine model for prediction of muscle forces

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Analytical musculoskeletal spine models have been used to investigate the mechanical behavior of the spine where experimental measurements are not possible.

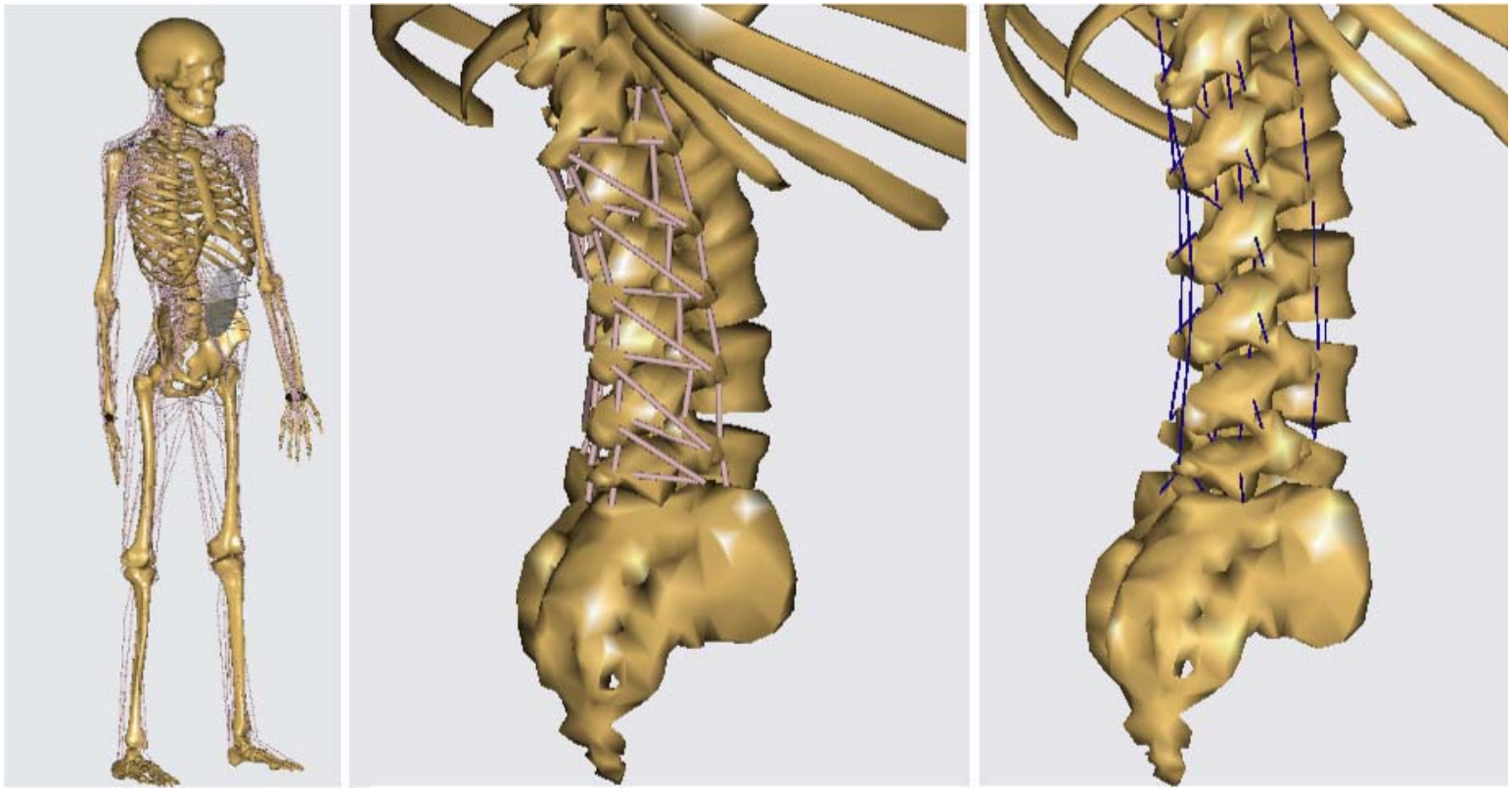
These models usually neglect or strongly simplify passive elements (ligaments and disc stiffness), short segmental muscles and the intradiscal pressure.

The aims of this study were

- to add short segmental muscles, ligaments, disc stiffness and intradiscal pressure to an existing inverse dynamic model;
- to validate the new spine model against experimental data;
- to provide the most important muscle forces for motions in the main anatomical planes.

Methods

A thoraco-lumbar spine model (Han et al. Med Eng & Phys, in press) using the AnyBody Modeling System (AnyBody Technology, Aalborg, DK) was created.



Full body musculoskeletal model (left), spine model with short segmental muscles (centre), spine model with ligaments implemented (right).

Additional spinal components and their material properties implemented in the base spine model

Components	Stiffness (Nm/°)
Flexion-extension	$-0.002x^3 + 0.0141x^2 - 0.4726x$
Lateral bending	$-0.0087x^3 - 0.6989x$
Axial rotation	$-0.0061x^3 - 1.0191x$

Disc stiffness

Variable x denotes rotational angle in each joint.

Activity	Range of IAP (kPa)
Standing, Sitting	0 – 1
Lateral bending, Axial rotation	0 – 2
Flexed activities	2.2 – 4.4

Allowed range of intra-abdominal pressure (IAP)

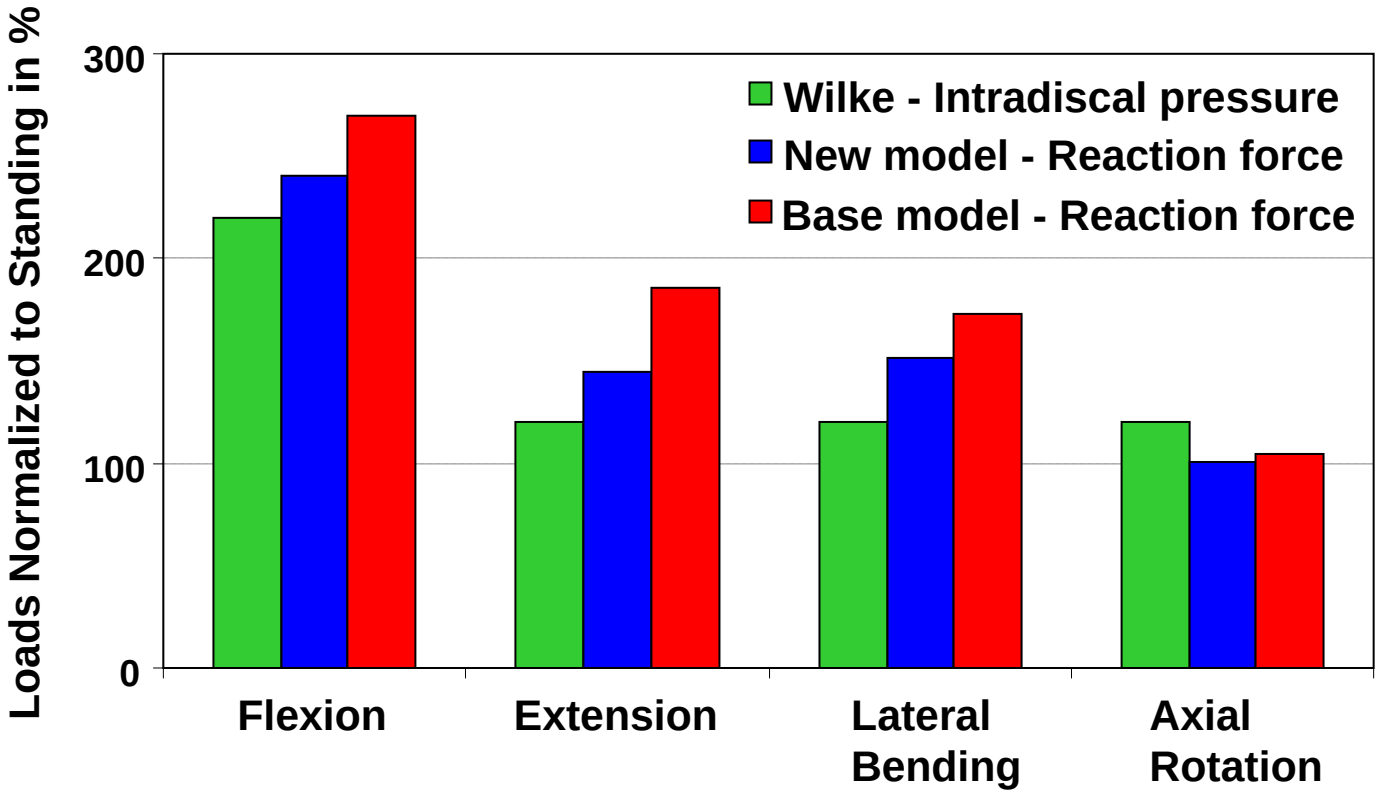
Ligaments' forces were implemented via an exponential function of their strain.

Han et al., Med Eng Phys (2011), doi:10.1016/j.medengphy.2011.09.014

Forces in the muscles were calculated for

- Standing
- Flexion
- Extension
- Lateral bending
- Axial rotation

Comparison of intradiscal pressure and normalized resultant joint forces at L4/L5 level



Good agreement between calculated (new model) and measured results could be achieved

Calculated muscle forces in N during different postures

Activity	LM	Ic	Lg	PsM	QL	EO	IO	Ss	TM	RA	LD
Standing	23	1	28	37	0	16	19	61	24	28	58
Flexion	92	137	146	0	0	17	33	29	17	0	18
Extension	11	0	18	70	13	4	24	35	15	363	0
Lateral Bending	53	23	44	144	24	67	105	79	25	36	90
Axial Rotation	25	9	25	81	3	30	29	77	33	55	48

LM = Lumbar Multifidus; Ic = Iliocostalis; Lg = Longissimus; PsM = Psoas Major;
QL = Quadratus Lumborum; EO = External Oblique; IO = Internal Oblique;
Ss = Semispinalis; TM = Thoracic Multifidus; RA = Rectus Abdominis;
LD = Latissimus Dorsi

The highest muscle force were predicted in the m. longissimus for flexion, in the m. rectus abdominis for extension, and in the m. psoas major for lateral bending and axial rotation.

The results of this study show that

- spinal components neglected in many models play a significant role in stabilizing the spine;
- an inclusion of these additional components into the base spine model improves the accuracy of estimated spinal loads;
- the enhanced model allows a more precise prediction of muscle forces.

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None of the authors has any potential conflict of interest

Thank you !