Customized MBD models to contribute to answering clinical questions about the spine in motion

Maxime Raison[1], Aubain Verlé[2], Gabriel Abedrabbo[2], Christine Detrembleur[3], Philippe Mahaudens[3] and Paul Fisette[2]

[1] Department of mechanical engineering, Polytechnique Montreal, maxime.raison@polymtl.ca
[2] Institute of Mechanics, M*aterials and Civil Engineering, Université catholique de Louvain, {aubain.verle,gabriel.abedrabbo,paul.fisette}@uclouvain.be*
[3] Faculty of Motor Sciences, Université catholique de Lo*uvain, {christine.detrembleur,philippe.mahaudens}@uclouvain.be*

Context: The biomechanical analysis of the spine is essential to monitor orthopedic and physiotherapy treatments in patients with idiopathic scoliosis [1,2]. This analysis is significant in dynamic conditions, particularly during gait where the metabolic cost of scoliotic patients is ~30% higher than the one of healthy subjects [3]. Today, the clinical professionals regularly ask biomechanical questions (Q) that could orient their therapeutic choices, and to which researchers in multibody dynamics (MBD) modeling could answer, e.g.:

Q1: What is the impact of walking speed on joint efforts at the level of the lumbo-sacral joint, and therefore potentially on the impact on scoliosis according to the Hueter-Volkmann criterion?

Q2: According to which mass and which left-right mass distribution can the wearing of some orthopedic brace influence the comfort speed during gait? This information would constrain the design of braces.

Q3: What is the relationship between 1. the mechanical energy of the spine computed from the spine joint powers and 2. the metabolic cost of the subject during gait? This metabolic cost is usually computed with a specific equipment measuring the maximum oxygen consumption (VO2max), defined as the maximum volume of oxygen consumed by the subject per unit of time.

However, MBD models currently developed for scoliosis are usually complex and not yet transferred to clinics at this stage to allow clinicians to autonomically carry out scoliotic gait analyzes. Thus, for the expertise in MBD to be able to serve today the concrete needs of clinicians, it would be necessary to quickly answer questions from clinicians because these ones must make therapeutic decisions, and to adapt to their clinical cases that are constantly evolving. The objective of this study is to evaluate if the expertise in MBD modeling could be used to answer biomechanics questions of clinicians, especially Q1-3 above, through simplified and customized models according to their questions, rather than via a generic model.

Methods: The walking tests were performed by one subject on a custom-made treadmill at various walking speeds: 1km/h ("slow"), 4km/h ("standard"), and 7km/h ("fast"). Kinematics, i.e. the Cartesian coordinates, $\boldsymbol{X}_{exp}$, of the optokinetic sensors placed on the anatomical landmarks, was recorded by an 8-camera 3D motion analysis system (Smart-DX, BTS, Milan, Italy) at a sampling frequency of 200 Hz. Metabolic cost was computed from VO2max recorded by a Quark b2 device (Cosmed, Rome, Italy). To answer questions from clinicians within four months, the project was conducted in the context of a technological project followed by 9 groups of 4 students. The management team consisted of two teachers in physiotherapy leading the gait analysis at the beginning of the session, and four teachers in MBD for the rest of the project. On the project time, the students were first introduced to biomechanics, MBD kinematic and dynamic processes, and an MBD software (Robotran [5]). In the customized MBD model (Fig. 1A), the pelvis kinematic was imposed in positions, velocities, and accelerations, the associated forces and torques being equal to the Lagrange multipliers. So the lower limbs and the ground reaction forces were not necessary. Successively, the joint relative coordinates were optimized thanks to a direct kinematic identification that best fitted the corresponding Cartesian coordinates to the experimental data, then the joint efforts were obtained by an inverse dynamic model (Fig. 1B), and finally the joint power and the corresponding mechanical energy were classically computed.

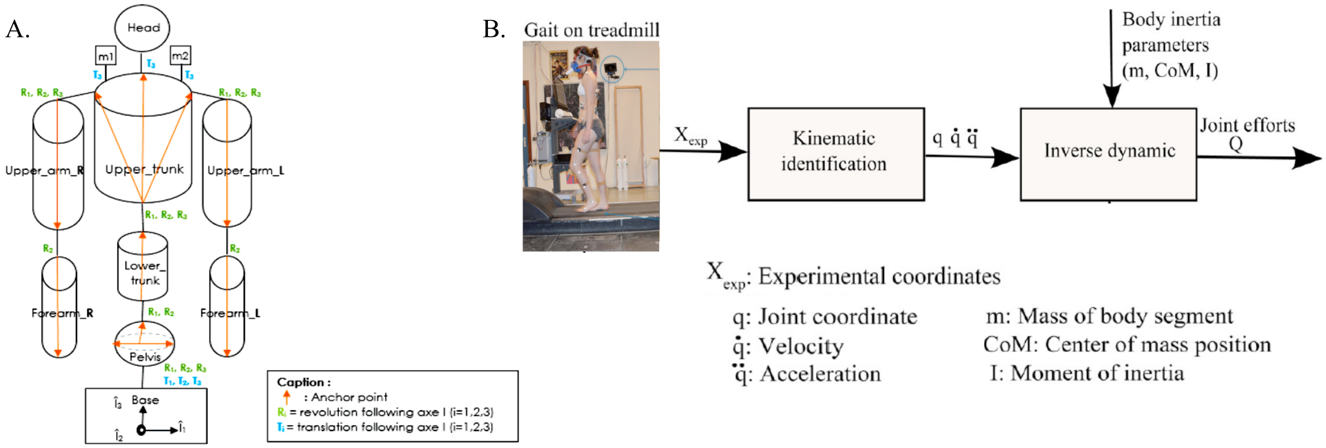
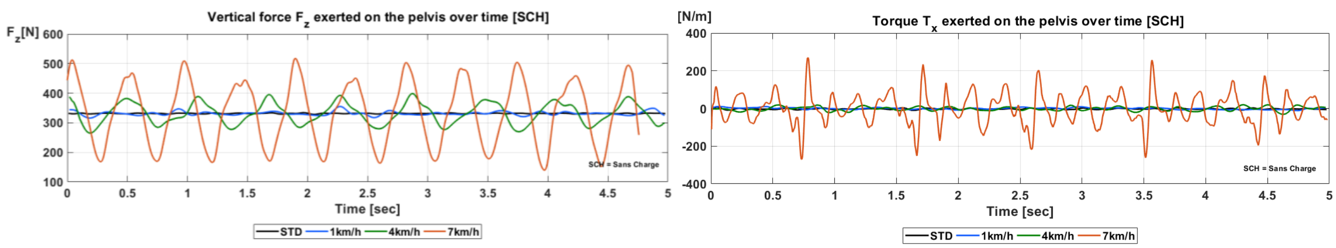


Fig. 1: A. Customized MBD model to answer Q1-2. B. Process of joint effort computation using the MBD model.

Results: Fig. 2A and B respectively presents longitudinal forces ($\boldsymbol{F_z}$) and antero-posterior torques ($\boldsymbol{T_x}$) at the lombo-sacral joint. Fig. 2C and D highlight the dynamic contributions to these efforts during gait at 1, 4, and 7 km/h. Results on the mechanical energy of the spine at 1, 4, and 7 km/h will also be presented at the conference and compared to the metabolic cost, to answer to Q2-3.



Fz	1km/h	4km/h	7km/h
Static	331,32	331,32	331,32
Dynamic contribution (>STD)	340	388	486
Dynamic contribution(<STD)	324	278	167

Tx	1km/h	4km/h	7km/h
Static	-2,74	-2,74	-2,74
Dynamic contribution (>STD)	6	12	135
Dynamic contribution(<STD)	-5	-13	-121

Fig. 2: A. Longitudinal forces ($\boldsymbol{F_z}$) and B. antero-posterior torques ($\boldsymbol{T_x}$) at the lumbo-sacral joint. C-D. Dynamic contributions to these efforts during gait at 1, 4, and 7 km/h. STD = standard deviation of the static component of the effort.

Discussion and conclusion: The results of Fig. 2 contribute to answering to Q1: gait speed has an influence on the amplitudes of $\boldsymbol{F_z}$ and $\boldsymbol{T_x}$ at the lumbo-sacral joint computed via the MBD model. This result shows that the expertise in MBD modeling can contribute to answering current biomechanics questions of clinicians, especially Q1 above, through simplified and customized models according to their questions. Complementary results of mechanical energy of the spine and metabolic cost at 1, 4, and 7 km/h will be presented at the conference to show the impact of additional loads on comfortable gait velocity (Q2) and energy consumption (Q3). A perspective could be to extend this tool to contribute to international competitions, such as the Grand challenge to predict *in vivo* knee loads [5].

Acknowledgements: We thank the students from *Technological and Quantitative Project LLSMF2018*, UCL.

References

[1] Abedrabbo G. *Quantification of intervertebral efforts using a multibody dynamics approach: application to scoliosis*. UCL Thesis, Louvain-la-Neuve, January: 166p, 2017.

[2] Yazji M et al. Are the mediolateral joint forces in the lower limbs different between scoliotic and healthy subjects during gait? *Scoliosis* 10(2):S3, 2015.

[3] Mahaudens P et al. Gait in adolescent idiopathic scoliosis: energy cost analysis. *Eur Spine J.* 18(8):1160-8, 2009.

[4] Samin JC, Fisette P. *Symbolic Modeling of Multibody Systems*. Kluwer Acad. Publ. 2003: 476p, 2003.

[5] Fregly BJ et al. Grand challenge competition to predict in vivo knee loads. *J Orthop Res.* 30(4):503-13, 2012.