

Customized MBD models to contribute answering clinical questions about the spine

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ABSTRACT —Monitoring orthopedic and physiotherapy treatments in scoliosis patients requires biomechanical analysis of the spine. This analysis is significant in dynamic conditions, particularly during gait where the metabolic cost of scoliosis patients is ~30% higher than the one of healthy subjects. Regularly, therapists and other clinical professionals ask biomechanical questions that could orient their therapeutic choices, and to which researchers in multibody dynamics (MBD) modeling could answer, for example: 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? Nevertheless, MBD models currently developed for scoliosis are usually complex and not yet transferred to clinics at this stage to allow clinicians to autonomously 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 was to evaluate if the expertise in MBD modeling could be used to answer biomechanics questions of clinicians, through simplified and customized models according to their questions, rather than via a generic model. The results contribute to answering to the following question: gait speed has an influence on the amplitudes of the longitudinal force, F_x , and the antero-posterior torque, 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, through simplified and customized models according to their questions. A perspective could be to extend this tool to contribute to international competitions, such as the Grand challenge to predict in vivo knee loads.

1 Introduction

The biomechanical analysis of the spine is essential to monitor orthopedic and physiotherapy treatments in scoliosis patients [1,2]. This analysis is significant in dynamic conditions, particularly during gait where the metabolic cost of scoliosis patients is ~30% higher than the one of healthy subjects [3]. Today, the professionals in clinics 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 corsets.

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 autonomously 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 was 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.

2 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, 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 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, course named *LLSMF2018 - Technological and Quantitative Project* at UCL, 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. The approach adopted was that of tripartite gain ("win³") for 1. professionals (here clinicians), 2. students and 3. researchers. The course schedule is illustrated in Fig 1.


		Theoretical sessions	Practical sessions	
Pre-project	1	Administration		
	2	Tool training : 	Model drawing	
	3	Direct and inverse dynamics	Direct and inverse dynamics analysis	
Spine project	4	Laboratory : Walking test	Laboratory data treatment	→ Deliverable 1
	5	Biomechanics of the spine	Model drawing of spine	
	6	Restructuring	Model parametrization	
	7	Restructuring	Inverse kinematics analysis	→ Deliverable 2
	8	////////////////////	////////////////////	
	9		Effort determination	
	10		Deepening subject development	
	11		Deepening subject development	
	12		Result analysis	
	13	Oral presentation		→ Deliverable 3

Fig. 1: Schedule of the course *LLSMF2018 - Technological and Quantitative Project* at UCL, to conduct this project

To summarize this course schedule:

First on the project time, the students were first introduced to biomechanics, MBD kinematic and dynamic processes [4] (Fig. 2), and an MBD software (Robotran [5]).

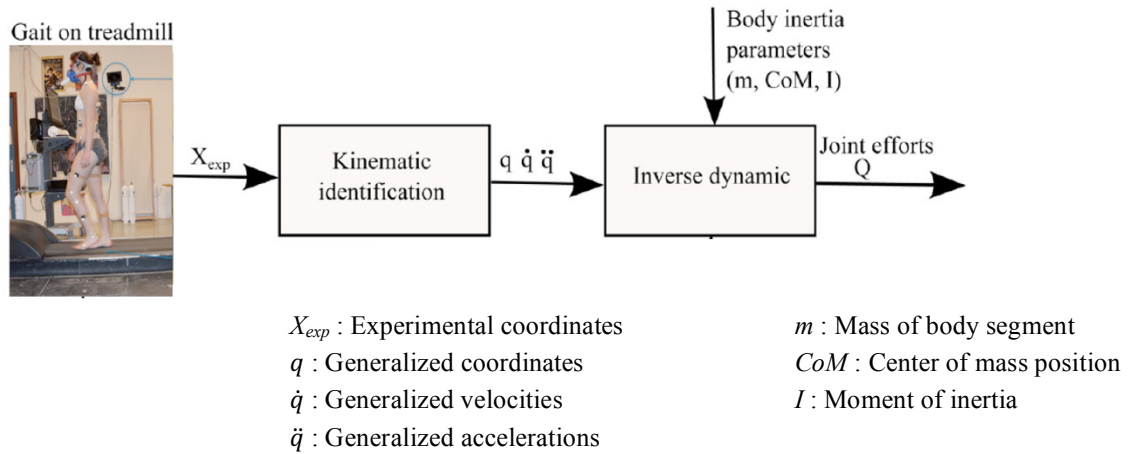


Fig. 2: Process of joint effort computation.

This learning was achieved through a pre-project involving a simplified spine model (Fig. 3): the pelvis kinematics 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.

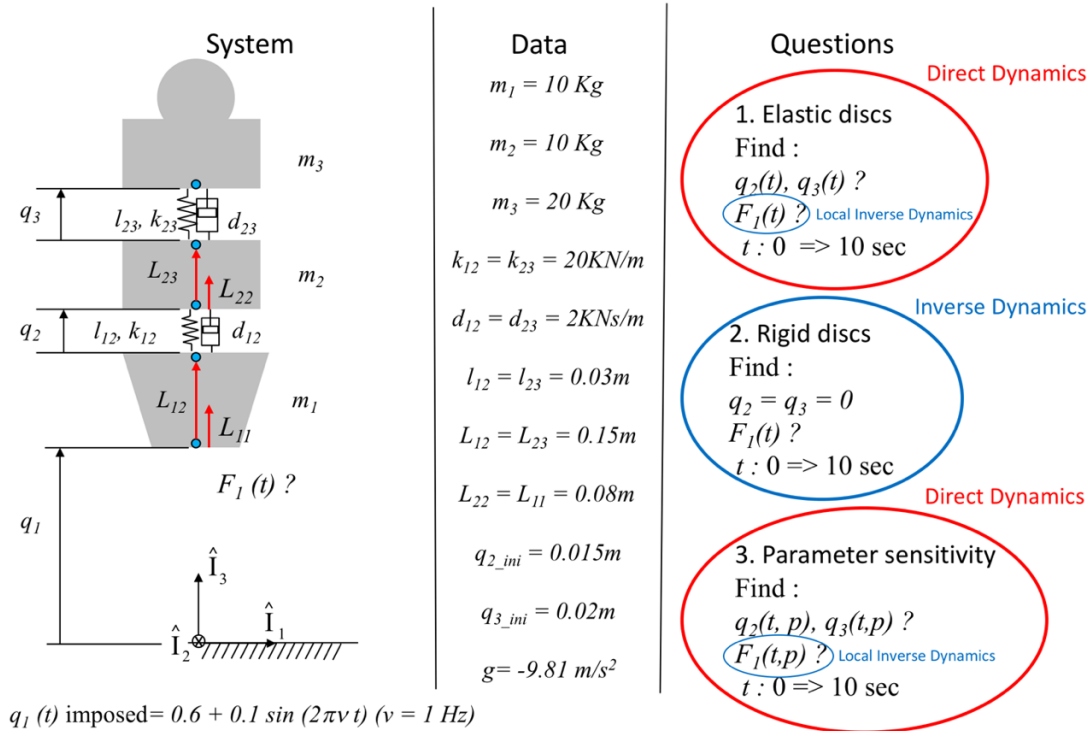


Fig. 3: Pre-project involving a simplified spine model.

Successively, the joint relative coordinates were optimized thanks to a direct kinematic identification that best fitted the corresponding Cartesian coordinates to the experimental data (Fig. 4), then the joint efforts were obtained by an inverse dynamic model (Fig. 2), and finally the joint power and the corresponding mechanical energy were classically computed.

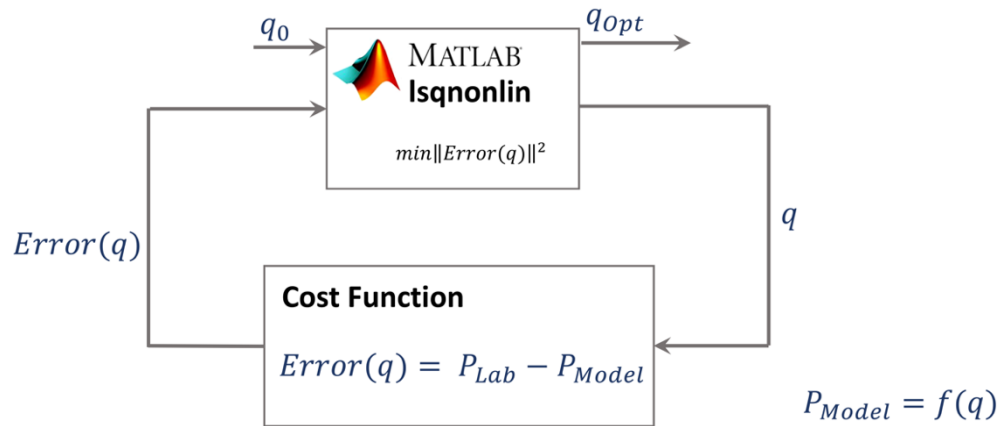


Fig. 4: Direct kinematic identification that best fitted the corresponding Cartesian coordinates to the experimental data.

Secondly on the project time, to answer Q1-2, the student groups developed their customized MBD model (Fig. 5), more complex than the pre-project model, and adapted the process described in Fig. 2 to their model.

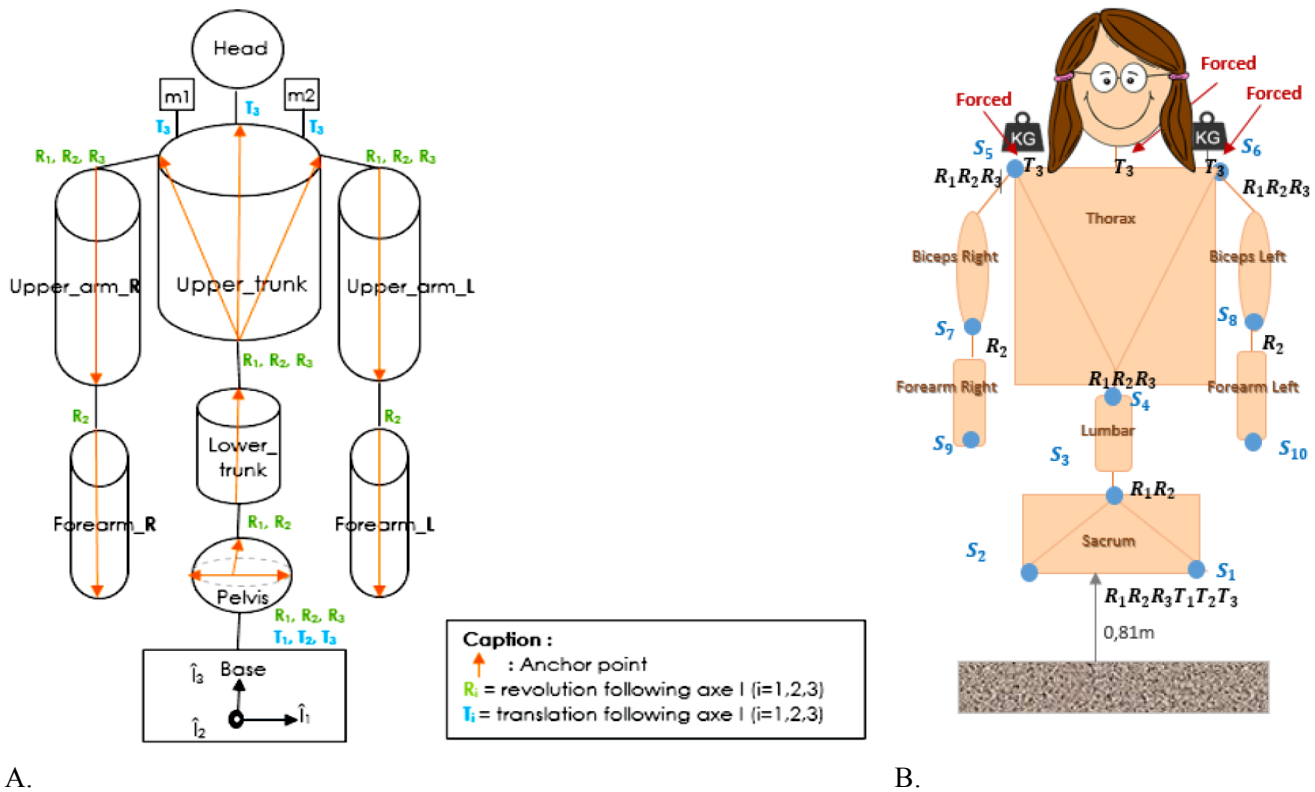


Fig. 5: Two examples of customized MBD models developed by the student groups to answer to Q1-2.

3 Results

Fig. 6A and B respectively presents longitudinal forces (F_z) and antero-posterior torques (T_x) at the lombo-sacral joint.

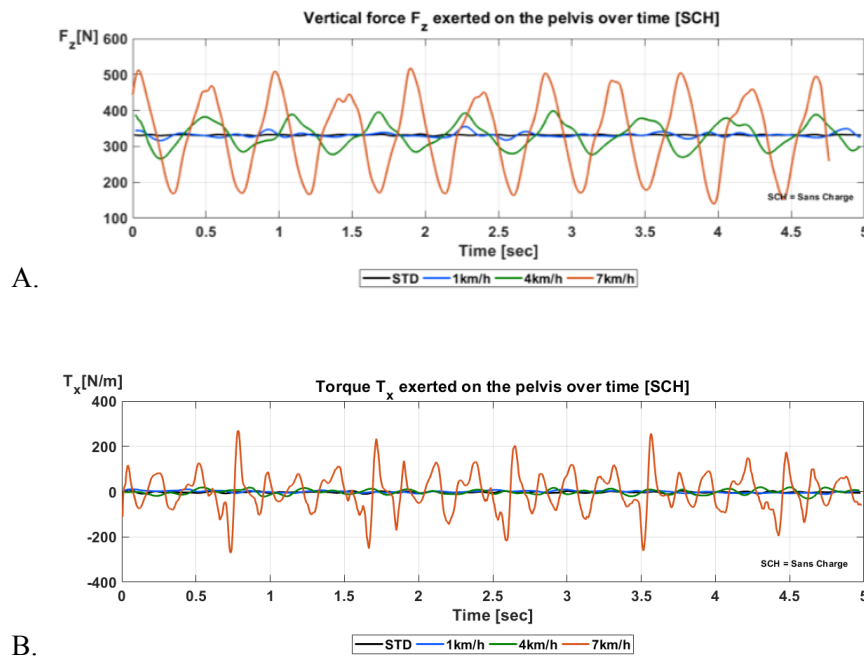


Fig. 6: A. Longitudinal forces (F_z) and B. antero-posterior torques (T_x) at the lumbo-sacral joint.

Fig. 7A and B 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.

A.

F_x	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

B.

T_x [SCH]	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. 7: Dynamic contributions to A. the longitudinal forces (F_z) and B. antero-posterior torques (T_x), during gait at 1, 4, and 7 km/h.

4 Discussion and conclusion

The results of Fig. 6-7 contribute to answering to Q1: gait speed has an influence on the amplitudes of longitudinal forces, F_z , and antero-posterior torques, 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 [6].

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