Dynamic Analysis of the Spine: Impact of the Internal Organs Wobbling Motion During Gait

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Context and Objective

The intervertebral efforts quantification in scoliotic spines, before and after spine arthrodesis, appears to be useful for surgical planning. An increase of 30% of the energetic cost for adolescent idiopathic scoliosis patients [1], as well as its consequences in ordinary living, suggest that gait is a relevant motion to be considered in our study.

The accurate computation of those efforts strongly depends on 4 pillars: geometrical identification, spine and pelvis kinematics, patient physiology and muscular forces. The geometrical identification of the spine, using bi-planar X-rays (Fig 1-left)), as well as the computation of its kinematics from a limited amount of data (Fig 1-right)), has been addressed in previous studies [2], [3]. The present work focuses on the patient physiology, and more particularly on the motion of the organs inside the abdominal cavity and its impact on the intervertebral efforts during gait.

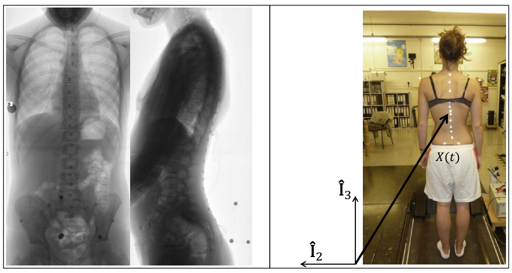

Figure 1: Spine Geometrical and Kinematic identification [2], [3].

Methodology

To study the physiology of the human body, via a multibody model [4], we have subdivided it into different parts: head, thorax, upper limbs, abdominal cavity, spine, pelvis and lower limbs (deliberately absent from the model [3]). During smooth gait, the head, the thorax and the upper limbs could be considered as a sequence of polyarticulated musculoskeletal rigid bodies. However, this is not the case for the abdominal cavity, where the organs are wobbling masses and not directly connected to the spine.

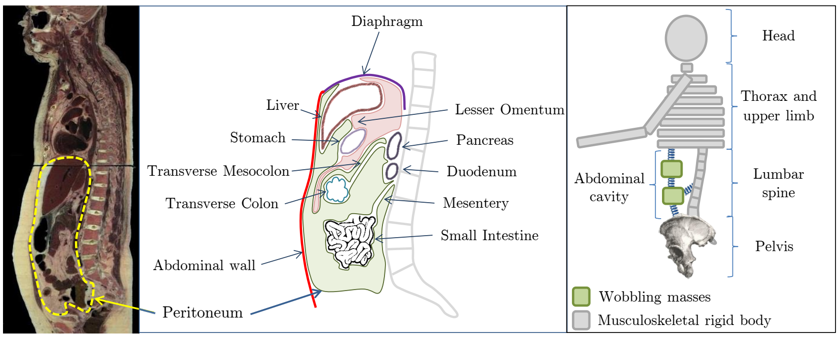

Figure 2: Development of the multibody model (right) of the abdominal cavity, based on patient physiology[1] (left, middle)

In [5], an equivalent model (i.e. not based on patient physiology) that reproduces the resonance modes of the visceral organs was developed. However, this model was not originally designed to analyse the impact of these wobbling organs on the intervertebral efforts.

[1]From University of Michigan: http://vhp.med.umich.edu/browsers/female.html

Taking into account of visceral organs for our study is a delicate task that has required judgement from both physiotherapist and engineers. As we can observe in Figure 2-middle, it is possible to identify three kinds of attachment in the abdominal cavity: 1) "strong" anchor to the diaphragm and/or the spine; this is the case for the liver, the pancreas and the duodenum; 2) "weak" connection between bodies maintained by the peritoneum; this is the case for lesser omentum, which connects stomach and liver, the transverse mesocolon, which connects the pancreas and the transverse colon, and for the mesentery, which connects the small intestine to the lumbar spine. 3) Finally, the direct surface contact between organs and the abdominal wall (Fig 2-left). Although it is difficult to accurately identify the location and the mechanical properties for each of those attachments, a multibody model is proposed (Fig 2-right). In order to identify the impact of the abdominal cavity on the spine efforts during gait. The proposed variants of the model are the result of intense exchanges with physiotherapists and anatomy professors of UCL, to avoid the development of an unduly complicated model (in terms of size and parameters to be identified) regarding our project issue. In this model, the visceral wobbling masses are subdivided in two: the upper mass represents the liver and the stomach, and the lower mass refers to the intestines. Then, in order to analyse the sensitivity of the attachment characteristics, three variants are proposed. In (Fig 3-a), three vertical springs/dampers are used to connect the two masses between the thorax and the pelvis; in (Fig 3-b), the same, but without spring – just a damper – between the two wobbling masses; and in (Fig 3-c), we included a spring/damper connection that represents the mesentery (Fig 2-middle). Finally, a reference model, in which all visceral masses are neglected is also considered for this study.

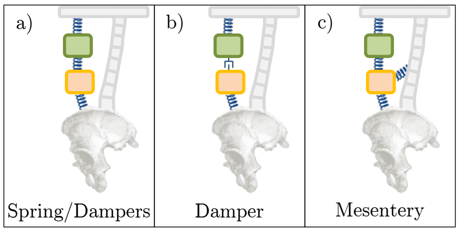

Figure 3: Variants of the multibody model

Preliminary Results and Conclusion

A preliminary analysis reveals a rather low sensitivity of the vertical intervertebral efforts with respect to the organs dynamics and its modelling parameters. In Fig 4, a difference of around 10% is observed for the vertical intervertebral force between L4 and L5 between model b. (Fig 3-b) and the reference model. Although model b. (Fig 3-b) appears to be the most relevant from a physiological aspects, the definitive choice of this variant requires further investigation and identification. Those are currently in progress for a non-scoliotic and for scoliotic patient, walking at different speeds.

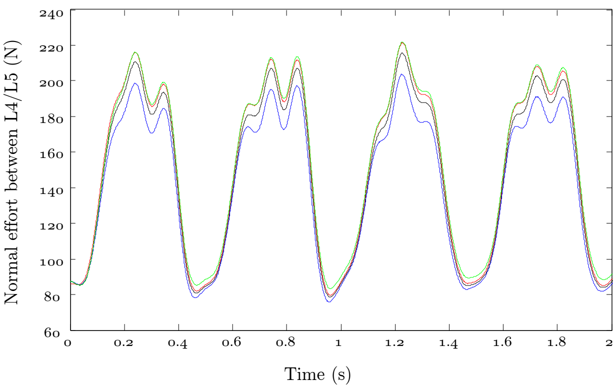

Figure 4: Normal effort between L4/L5 for different variants: for variant a (black), b (green), c (red) and the reference model (blue)

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