MRI-based musculoskeletal models for the quantification of gait in children with Juvenile Idiopathic Arthritis

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Abstract. Juvenile Idiopathic Arthritis (JIA) is a paediatric disease of unknown aetiology potentially leading to biomechanical alterations due to local damage of joints. After assessing its reliability, a patient-specific musculoskeletal model of the lower limb was used to investigate the link between joint loading and disease activity in a cohort of JIA children with ankle involvement. We observed a common strategy aiming at protecting the affected ankles with consequent overloading of hip and knee. When quantified at patient specific level, this strategy might allow to identify those cases where a localised steroid injection might not be sufficient to induce remission.

Keywords. Musculoskeletal, Patient-specific, Gait analysis, MRI, Juvenile Idiopathic Arthritis

Introduction. Juvenile Idiopathic Arthritis (JIA) is a paediatric disease of unknown aetiology characterised by joint inflammation potentially leading to cartilage damage [1]. Traditional gait analysis has been used for the investigation of locomotion in JIA patients [1], however, information about internal joint loading might provide further insight on the link between joint impairment and walking function and better inform treatment planning. Patient-specific musculoskeletal (MSK) modelling, leveraging on increased anatomical accuracy, can provide such information.

Research Question. Can MRI-based MSK models be reliably used in quantifying gait biomechanics in children with JIA?

Methods. Twenty children (Table 1) affected by JIA were recruited from two clinical centres as part of the MD-Paedigree project (EU, ICT program 600932). They underwent lower-limb medical resonance imaging (MRI) (T1-weighted e-THRIVE). The MRI-based clinical evaluation of the joints' inflammation allowed to divide the children in "non-active" group (NAG, n=10) and "active" group (AG, n=10). Stereo-photogrammetric gait analysis data and ground reaction forces were collected using the modified Oxford Foot Model [3] protocol. 3D bone geometries were segmented from the MRI to build personalised lower-limb MSK models (NMSBuilder [4]). The hip was modelled as an ideal ball-and-socket joint. Knee, ankle, and subtalar joints were modelled as ideal hinges. Joint axes were identified using morphological fitting. Walking simulations were run (Opensim [5]) to estimate the gait biomechanics. Intra-operator repeatability of the procedure was assessed quantifying the standard deviation of the output over a subset of three patients (14±1 y.o., 69±7 kg, 1.63±0.10 m)). Joint kinematics and joint reaction force (JRF) of the two groups were then compared with 1D two-tailed t-test (α=0.05) based on Statistical Parametric Mapping (SPM) [6].

Results. Intra-operator variability was lower than 2° for the sagittal plane joint kinematics and lower than 0.6 BW for the three JRFs (Table 2). In the AG, increased hip and knee peak flexions in the

stance phase were associated to reduced ankle plantarflexion (4º, 9º, and 5º on average, respectively). No significant group differences were observed for the joint moments, whereas higher hip (1 BW) and knee (0.7 BW) JRFs were observed for the AG during the load acceptance phase (Figure 1).

Discussion. The repeatability of the developed modelling approach compared well with similar studies on adult patients [2]. The reduced plantarflexion in the AG confirms literature findings reporting limited mobility in the affected joints [1]. Associated increased loading of the hip and knee, likely resulting from the attempt to protect the inflamed ankle joint, suggests a multi-joint approach to be preferred in treating these patients.

References.

1 Broström, Acta Paediatr, 2004
2 Martelli, Comput Met Biomech Biomed Eng 2014
3 Stebbins, Gait Posture, 2006
4 Valente, Comput Methods Programs Biomed, 2017
5 Delp, IEEE Trans. Biomed. Eng, 2007
6 Pataky, Comput Met Biomech Biomed Eng, 2012

Table 1 - Patients' anthropometric and clinical details

Patient	Gender [F/M]	Age [Y]	Height [m]	Weight [Kg]	BMI	Sub-type*	Affected (active) joint
1	F	10	1.39	41.0	21	PsA	-
2	F	15.5	1.61	68.0	26	Ext oligo	Ankle
3	M	14	1.74	76.5	25	Poly-	Ankle
4	F	11	1.45	54.0	26	Oligo	-
5	F	18.5	1.59	68.0	27	Ext oligo	Knee
6	F	16.5	1.68	83.0	29	Ext oligo	Ankle and Knee
7	F	14.5	1.65	54.5	20	PsA	Ankle
8	F	11	1.31	26.6	16	Poly-	Ankle
9	F	14	1.63	63.8	24	Poly-	-
10	F	9	1.29	32.5	20	Poly-	-
11	F	8	1.23	23.5	16	Oligo	Ankle
12	M	10	1.5	37.0	16	Oligo	-
13	F	8.5	1.4	25.0	13	Oligo	Ankle
14	F	7	1.28	23.0	14	UndA	Ankle
15	M	7.5	1.17	35.7	26	Oligo	-
16	F	13	1.68	49.0	17	Oligo	-
17	M	12.5	1.55	45.6	19	Oligo	-
18	M	10	1.36	32.0	17	Oligo	-
19	F	13.5	1.56	54.5	22	Oligo	-
20	F	13.5	1.54	63.5	27	Poly-	Ankle
Average	-	11.9	1.48	47.8	21	-	-
SD	-	3.2	0.17	18.6	5	-	-
Total	15F	-	-	-	-	-	5R/7L

* Oligo = Persistent oligoarticular JIA, Ext oligo = Extended oligoarticular JIA, PsA = Psoriatic arthritis, Poly- = Rheumatoid-factor-negative polyarticular JIA, UndA = Undifferentiated arthritis;

Table 2 - Intra-operator standard deviaiton (SD) of joint kineamtics and JRFs in the sagittal plane for three patients

	Joint Kinematics SD [°]			**JRFs SD [BW]**		
	Hip	Knee	Ankle	Hip	Knee	Ankle
P1	0.2	0.3	1.4	0.6	0.3	0.3
P2	0.7	1.3	1.4	0.5	0.3	0.4
P3	0.5	1.5	1.3	0.5	0.5	0.4

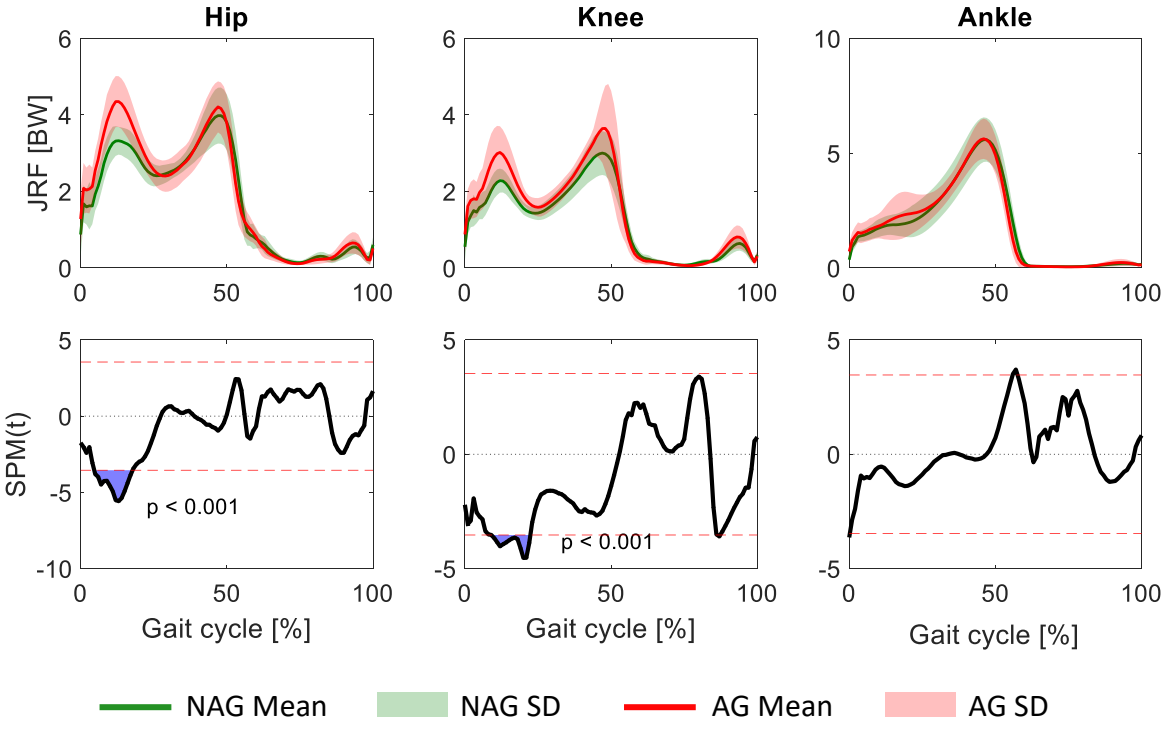

Figure 1 – JRFs and corresponding distribution of t-values (SPM(t)) with relevant supra-threshold cluster (blue) and p-values throughout the gait cycle for the non-active group (NAG) and active group (AG)