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Validation of a Model-Based approach for gait analysis.

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SUMMARY

To avoid inherent errors due to marker misplacement and displacement during motions using marker based system a Model-Base Approach has been created. This study presents the validation of this model for gait analysis.

INTRODUCTION

The use of gait analysis in daily clinics for patients' evaluation, diagnosis and follow-up (cerebral palsy, Parkinson disease, orthopedics' interventions…) is increasing. Stereophotogrammetric devices are the most used tool to perform these analyses [1]. Although these devices are accurate [2], results must be analyzed carefully due to relatively poor reproducibility [3]. One of the major issues is related to skin displacement artefacts. Motion representation is recognized reliable for the main plane of motion displacement, but secondary motions, or combined, are less reliable because of the above artefacts [4]. Model-based approach (MBA) combining accurate joint kinematics and motion data was previously developed based on a double-step registration method [5]. This study presents an extensive validation of this MBA method by comparing results with a conventional motion representation model (Plug-in-Gait or PIG).

METHODS

Twenty healthy subjects participated to this study (height=175±9cm, weight= 72±16kg, age= 24±2, 8 woman). This study was approved by the Ethical Committee of the Erasme Hospital (CCB : B406201112048) and written informed consent was obtained from all subjects prior to participation in the study.

Gait motion data were obtained from a stereophotogrammetric system (Vicon, 8 MXT40s cameras, Vicon Nexus software, frequency: 100Hz). Subjects were equipped with 20 reflective markers, 16 of them were used for the PiG model and 4 additional markers were used added for the MBA (Figure 1).

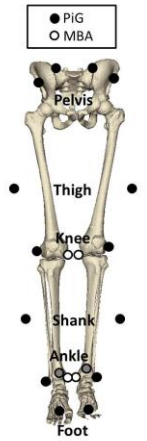

Figure 1: Markers used for PiG (in black) and for the MBA (same as PiG model plus the four displayed in white)

Figure 2 presents the processing of the raw trajectories for PiG and MBA.

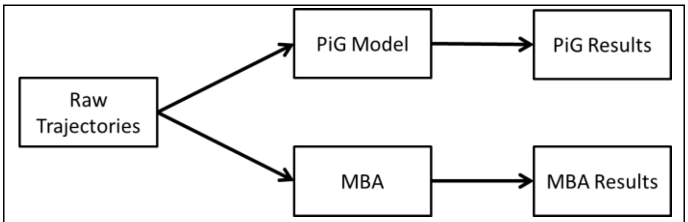

Figure 2: Post-processing of raw motion signals

Two trials were recorded for each subject. Normalized gait cycles (between two successive heel strikes) were obtained from these two trials for the PiG and MBA datasets.

Range of Motion (ROM), were computed (ROM=Maximal-minimal value) for pelvis, hip, knee and ankle joints. Difference between PiG and MBA were then computed. Paired-sample t-tests were used to compare both methods. Normalized Root-Mean Square Error (NRMSE) were also computed (as NRMSE=(RMSE/ROM)*100). Shapes of the curves were compared using Coefficient of Multiple Correlations (CMC).

RESULTS AND DISCUSSION

Results are presented in Table 1. During gait, the main motion displacements are performed along the sagittal plane (flexion-extension). No difference was found between the PiG and MBA for the main plane of motion during gait: NRMSE values were low (1% for hip and knee flexion, 3% for ankle dorsal/plantar flexion and 2% for anterior/posterior pelvis tilt). CMC were high (0.99, 0.92, 0.97, and 0.89 for pelvis, hip, knee and ankle respectively).

Associated motions showed highly significance differences for all motions and joints (ROM difference and NRMSE showed important variation with regard of joint and motion. However CMC are excellent except for hip rotation (CMC=0.53).

Due to markers displacement (skin artefacts) and palpation errors, results of motion analysis performed with marker based should system should be interpreted with caution especially for combined motions [6], and are only reproducible for a large range of motion [7]. According to this study, the proposed MBA [5] and PiG results are similar for the main plane of motion.

Statistically-significant differences were found for combined motions. This study does not allow us to determine what results are the best. However two elements prone in favor of the MBA model. Firstly, supplementary reflective markers are associated to the MBA model (see Fig. 1) to allow a better estimation of the knee and ankle functional axis. Secondly, the MBA is based on optimization equations collected on previous validated in-vitro [8] and in-vivo [9]. Such validation is important to obtain reliable information related to combined motions.

CONCLUSIONS

The MBA and PiG approaches shows similar results for the main plane of motion displacement, but statistically-significative discrepancies appear for the combined motions. MBA appear to be usable in applications requesting better approximation of the joints-of-interest thanks to the integration of validated joint mechanisms. Thanks to these mechanisms estimation, muscle behavior could be better understood and be integrated in further models integrating soft tissue artifacts with gait analysis to increase quality of the results [10].

ACKNOWLEDGEMENTS

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Table 1: Mean results for Range of Motion (std) for PiG, MBA and difference (PiG-MBA), values are expressed in degrees. Normalized Root-Mean Square Error (in percentage) and Coefficient of Multiple Correlation.

Joint	Motion	PiG	MBA	Difference	NRMSE (%)	CMC
Pelvis	*Anterior-posterior*	2 (0.6)	2 (0.5)	0 (1)	2	0.99
	Up-Down	8 (2)	2 (0.5)	***6 (3) ******	13	0.99
	Rotations	8 (3)	2 (0.5)	***7 (3) ******	24	0.99
Hip	*Flexion-Extension*	40 (14)	41 (14)	-1 (3)	1	0.92
	Adduction-Abduction	12 (4)	4 (1)	***8 (3) ******	15	0.72
	Rotations	13 (4)	2 (1)	***11 (3) ******	25	0.53
Knee	*Flexion-Extension*	60 (19)	56 (18)	3 (4)	1	0.97
	Adduction-Abduction	9 (3)	3 (1)	***6 (5) *****	13	0.85
	Rotations	15 (4)	3 (1)	***12 (4) ******	15	0.68
Ankle	*Dorsal/Plantar Flexion*	29 (7)	26 (6)	3 (4)	3	0.89
	Adduction-Abduction	2 (0.4)	2 (1)	0 (1)	13	0.78
	Rotations	15 (4)	3 (1)	***12 (3)******	17	0.65

*p<0.05 **p<0.01 ***p<0.001 (Paired sample t-test)