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EFFECT OF SOFT TISSUE ARTIFACT ON KNEE JOINT KINEMATICS USING CLUSTERS OF MARKERS OBTAINED FROM BI-PLANE FLUOROSCOPY

[1]Arnaud Barré, [2]Jean-Philippe Thiran, [3]Brigitte M. Jolles, [4]Nicolas Theumann, and [1]Kamiar Aminian
[1]Laboratory of Movement Analysis and Measurement (LMAM), EPFL, Lausanne, Switzerland
[2]Signal Processing Laboratory (LTS5), EPFL, Lausanne, Switzerland
[3]Department of Orthopaedic Surgery and Traumatology, CHUV and University of Lausanne, Lausanne, Switzerland
[4]Department of Radiology, CHUV and University of Lausanne and Clinique Bois-Cerf, Lausanne, Switzerland
email: arnaud.barre@epfl.ch, web: http://lmam.epfl.ch

SUMMARY

The present study proposes to assess the effect of global soft tissue artifact displacement (GSTAD) on knee joint kinematics during treadmill gait. A map containing the displacement of the markers apposed on the skin relatively to the underlying bone was created. Afterward, this map was used to extract clusters of 4 markers on areas that were the less and the most affected by GSTAD during the whole gait cycle.Finally, the estimation of knee joint kinematics was done.

The results showed that the area corresponding to the iliotibial band was the less affected by GSTAD. Moreover, we found that the estimated knee kinematics is still affected by errors between 1-8° and 3-11mm for the rotations and translations during gait.

INTRODUCTION

The location of markers and the number of markers used to create a technical frame (TF) associated with a segment is influenced by the soft tissue artifact (STA) [1]. Indeed, the complex and non-uniform deformation of the skin and underlying tissues generate noise on the estimation of TF's pose (orientation and position) which then influence the estimation of joint kinematics. Some studies already assessed the influence of markers' location on knee joint kinematics using different trio of markers on the thigh and the shank, without finding an optimal configuration [2]. This could be explained by the use of only 3 markers while it was suggested to use a minimum of 4 markers coupled with a least square pose estimator (LSP) to reconstruct the TF's pose [3]. Moreover, the quality of knee kinematics is highly dependent to the number of markers and their location. The use of a map representing the difference between markers' location registered on the underlying bone and on the skin could help to find the markers less affected by STA [4]. These markers could be then used to estimate a knee joint kinematics less affected by STA.

Therefore, the aim of this study was twofold. The first step was to find on both segments (thigh, shank) which areas were less and most affected by STA during treadmill gait. The second step was to select a cluster of 4 markers in these areas and see their influence on the knee joint kinematics. It is assumed that the knee joint kinematics estimated by the clusters of markers less affected by STA would be closer to the true knee joint kinematics in term of magnitude and pattern.

METHODS

A bi-plane fluoroscopic system (2 Philips BV Pulsera 300, 30Hz, 60kV, 5.95mA) coupled with a motion capture system (7 MX3+ cameras, Vicon, 240Hz) was devised to assess the GSTAD deformation map during treadmill gait. 19 subjects having knee F.I.R.S.T prosthesis (Symbios, CH) were evaluated in this system. The mean and standard deviation (SD) of age, weight and height were 70 (6) years, 80 (14) kg, and 168 (9) cm respectively. 80 markers (Ø 4mm) were apposed on the frontal and lateral sides of the thigh, and on the lateral, frontal, and medial sides of the shank. A gait acquisition of 15 seconds at comfortable speed was recorded and followed by a static acquisition.

The motion of the femur and the tibia was reconstructed using the software MB-RSA (Medis Specials, NL) and based on bi-plane fluoroscopic data and 3D models of the prosthesis. The reconstructed poses were used to describe the motion of the bone and were considered as their anatomical frame (AF). The definition of the cluster of markers on the thigh and the shank was realized during the static acquisition. The motion of these clusters during the gait acquisition was reconstructed using a least square pose estimator (LSP) and then downsampled at 30Hz. The computation of the STA map on each segment was realized as the following. Firstly, during the static acquisition, the markers were registered into the reference frame of the bone as well as in the TF of the segment. Then, during the gait acquisition, the trajectory of these markers were recreated based on the motion of the prosthesis component ($\mathbf{p}_{PT}(t)$) as well as the motion of the cluster ($\mathbf{p}_{CL}(t)$). The difference ($\mathbf{d}_{GSTAD}(t)$) between both reconstructions was then expressed in the prosthesis reference frame to finally represent the global soft tissue artifact displacement (GSTAD). The GSTAD was then defined as the rigid body motion of the cluster relative to the underlying bone. The norm of these differences were calculated, normalized, and averaged over the first 7 detected gait cycles (GC). Secondly, a cylinder best fitting method was applied on the markers registered in the prosthesis reference frame to model the cloud of markers. Each marker was projected on this cylinder. The cylinder was then unwrapped to create a grid for each subject, where height and width of the grid correspond to the height and circumference of the segment respectively. All the grids were then normalized to a common size and then averaged. The norms of the differences ($\mathbf{d}_{GSTAD}(t)$) were associated with the average grid and create an unstructured grid, which was interpolated by a barycentric method to create a structured grid (cell size: 10 mm) representing the STA map.

Based on the STA map for the thigh and the shank, markers less affected and most affected by STA were extracted to create two clusters of 4 markers. Procedures to estimate knee joint kinematics were then realized. During the static calibration, TFs were constructed as well as their corresponding AF-TF rigid transformation matrix. TFs pose during gait acquisition were computed with a LSP. The knee joint kinematics was estimated as defined by the joint coordinate system [5], normalized by gait cycle and averaged over the 7 first gait cycle of each subject. The quality of estimated knee joint kinematics parameters (flexion-extension: FE, abduction-adduction: AA, internal-external rotation: IE, latero-medial: LM, postero-anterior PA translation, and distraction-compression: DC) were compared to the kinematics measured by the bi-plane fluoroscopic system in term of root mean square error (RMSE).

RESULTS AND DISCUSSION

The GSTAD map for the thigh averaged over the whole gait cycle is illustrated in the Figure 1. One area located approximately in the iliotibial band region was less affected by GSTAD (2-11mm), while the region over the upper part of the Sartorius muscle was the most affected by GSTAD (15-20mm). The region over the rectus femoris muscle has an error around 13-17mm. For the shank, all the errors were below 5mm. Therefore, only one cluster on the lateral side of the shank was extracted to represent the less affected cluster.

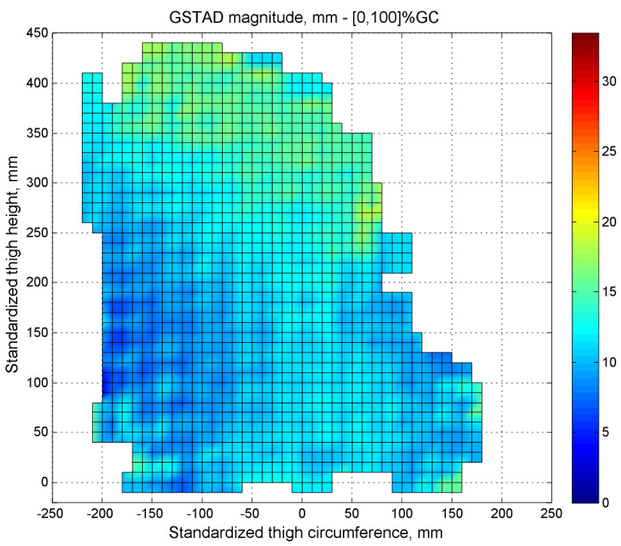

Figure 1: Averaged (n=19) STA map for the right thigh during gait cycle. The negative value on the horizontal axis represents the lateral side of the thigh.

A total of 11 subjects had at least 4 markers in each of these areas. Compared to the estimated knee kinematics based on the full clusters (using all markers), the less affected cluster gave only better results for FE and PA during 0-60% of the GC (Table 1). This confirmed partially our initial hypothesis, which assumed that cluster of markers less affected by GSTAD will give results close to the true knee kinematics. This is also supported by the results of the most affected cluster, which had large differences during all the gait cycle compared to the full and less affected clusters. Only estimated IE for the most affected cluster had a better result than for less affected cluster during 60-100% of the GC. Compared to the full cluster, which represent the general trend of GSTAD and required to spread ~40 markers on the whole segment, the use of a cluster of 4 markers on the iliotibial band area could represent the same behavior.

Table 1: Average (n=11) RMSE between the knee kinematics measured by the bi-plane fluoroscopic system and the kinematics estimated by clusters of skin markers.

	RMSE Knee joint angle, °					
	0-60 %GC			60-100 %GC		
Clusters	**FE**	**AA**	**IE**	**FE**	**AA**	**IE**
Full	1.6	1.3	4.1	4.0	3.1	3.9
Less affected	0.5	1.6	5.8	4.4	4.4	8.0
Most affected	3.1	3.1	6.2	5.5	9.3	6.1
	RMSE Knee joint translations, mm					
	0-60 %GC			60-100 %GC		
Clusters	**LM**	**PA**	**DC**	**LM**	**PA**	**DC**
Full	2.5	4.2	2.8	5.2	6.7	6.3
Less affected	2.9	3.0	3.7	5.0	6.0	10.8
Most affected	13.3	11.5	10.3	30.7	15.2	17.3

As all the surface of the thigh and the shank was influenced by GSTAD, the use of a compensation method is required. The simplest method could be to represent GSTAD as a systematic error over the gait cycle and compensated directly on the estimated knee kinematics or on the pose of the segments. Next investigations will analyze GSTAD patterns for these clusters and also for different clusters defined as a mix between less, medium and most affected areas. One goal could be to model GSTAD as a helical motion driven by joint kinematics and personalized to subject's information.

CONCLUSIONS

This study proposed to create a map representing the displacement of the markers relative to the bone for the thigh and the shank during treadmill gait. This map conducted to the finding of an area less affected by GSTAD. The results with 4 markers in less affected area are similar or better (except for IE and DC) than those obtained with the cluster using a high number of markers. Further analyses will determine patterns' similarities with the true knee kinematics.

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