Quantitative evaluation of Evoke knee orthosis using EOS biplane X-ray images during squat movement

Preliminary Results

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PREFACE

This project was performed in the framework of an industrial collaboration with the company Medicus during May 2015 – November 2017. The aim of the project was to assess the new orthosis recently developed by Medicus Company. The general investigation was to compare contact point locations of OA subjects during a quasi-static task with and without wearing a knee orthosis in multiple squat postures. Our hypothesis was that the knee orthosis influences the tibiofemoral contact point locations in OA subjects and shifts the contact point location laterally on both the medial and lateral compartments. The following text addresses the finding of this experimental study. This could be seen as a proof of concept for the use of contact point locations as a parameter for evaluating the effectiveness of knee orthoses.

1. INTRODUCTION

Knee orthoses are medical devices intended to stabilize or limit the movement of the knee. The considerable increase in the supply of these devices has not been followed by an evaluation of the real effectiveness of these orthoses, both in terms of the postulated physiological effects or the therapeutic effects in the short or long term. Knee orthoses are classified into three groups: functional, rehabilitation, or prophylactic (Thoumie, Sautreuil, & Mevellec, 2001). In this project, we will focus on functional orthoses, particularly, in case of medial compartment knee osteoarthritis (OA). Previous works attempted to test the concept of reducing the stresses on the medial compartment of the knee during walking with the use of a valgus orthosis and Matsuno, Kadowaki, et Tsuji (1997) showed a reduction in pain as well as a 16% improvement in quadriceps strength in about 20 subjects with internal compartment knee osteoarthritis over a period of 12 months. Komistek et al. (1999) showed, with dynamic fluoroscopy, a 2-mm increase in joint space in the tibiofemoral joint and a reduction in pain in 80% of subjects. A more recent meta-analysis conducted by (Moyer et al., 2015) on valgus orthoses showed a significant reduction in the external adduction moment (KAM) at the joint knee level during walking. Furthermore, this meta-analysis revealed that the biomechanical parameters most often used in the measurement of the results are: the KAM during the stance phase (17 studies), followed by the alignment in the frontal plane (11 studies), external flexion-extension moment (KEM) (4 studies), joint space narrow (4 studies), measured forces on the orthosis (3 studies), computed contact forces as well as muscle activations (2 studies). Most of these studies were performed with fixed-axis and fixed valgus design orthoses. In addition, and at our knowledge 3D joint kinematics and tibiofemoral contact point locations have never been measured in past. The company Médicus has developed a new orthosis (Evoke) with a light yet strong material which is adjusted to the morphology of the subject through 3D printing of the brace. The orthosis has a hinge with a polycentric axis capable of generating an articular coupling between flexion/extension and internal/external rotations close to joint kinematics of the normal knee as assessed in earlier study on cadaveric specimens (P. Walker, Kurosawa, Rovick, & Zimmerman, 1985). Our hypothesis is that this new orthosis, while limiting unwanted movements of the knee, gives it a dynamic and kinematics close to the healthy knee. The goal of this project is to accurately assess the immediate effect of wearing Evoke knee orthosis on 3D kinematics, tibiofemoral contact points, as well as the ground reaction forces and moments during a controlled squat movement using biplanar low dose x-ray (EOS).

2. METHODS

2.1 Subjects

Six subjects (N=6) with severe medial knee osteoarthritis participated in the project with a Kellegren-Laurence grade 4. Table -1 show the inertial characteristic of our subjects.

Table1: Inertial characteristic of subjects

ID	Date first visite	Age	Gender	Weight (Kg)	Height (m)	side	**date biomechanical assessment**	CHUM Identifier
1	19-Jun-17	77	F	86.2	1.55	R	03.10.2017, 16:30	820045
2	05-Jul-17	62	M	82.6	1.77	R	01.10.2017, 09:30	1378446
3	28-Jun-17	68	F	89.8	1.70	L	01.10.2017, 13:00	2186466
4	03-Jul-17	55	F	127.0	1.78	L	01.10.2017, 14:30	1171540
5	26-Jul-17	73	F	65.8	1.60	R	01.10.2017, 11:30	884892
6	06-Jul-17	59	M	111.1	1.78		-	565181
7	14-Jul-17	76	F	62.6	1.63		-	733849
8		64	F	56.7	1.63		-	7140991
9		54	F	79.8	1.57	R	01.10.2017, 16:00	384696
10		79	F	67.6	1.65			127652

A personalized Evoke orthosis was fabricated for each participant at Médicus laboratory. A 4-week adaptation period is required for wearing the orthosis before doing the test. The subjects performed the test 12 weeks after receiving the orthosis. Two Knee injury and Osteoarthritis Outcome Score (KOOS) questionnaires were filled by the subject at the time of first clinical evaluation and again after the adaptation period upon arrival for doing the experiments. All the subjects completed the consent form approved by the CRCHUM and ETS ethics Committees.

2.2 Experimental protocol

Each subject adopted five (5) weight-bearing squat postures from the standing to a maximum flexion of 70^{o} i.e. at 0^{o}, 15^{o}, 30^{o}, 45^{o}, and 70^{o} knee flexion. The subject then performed the same 5 postures while wearing the orthosis. A positioning support with adjustable height helped the participant to keep the posture. For each of the 10 postures a pair of EOS biplane images was acquired. To ensure that the posture is the same with and without the orthosis, 3 inertial APDM sensors were placed on the shank, thigh, and sternum to control the knee flexion/extension angle and trunk inclination in real-time. The posture was monitored and then adjusted by the subject if necessary.

An AMTI force platform (ORS-6) was fixed inside the EOS cabinet to measure the forces and moments under the studied foot. A platform was deigned to isolate the reaction forces under the contralateral foot while both feet are maintained at the same level (Fig. 1). The spacing between the feet was defined so that the distance between the external malleoli corresponds to the inter-acromion gap at the shoulder in standing position.

Figure 1: Force platform in the EOS cabinet measures the forces under the studied foot in the middle while the contralateral foot is isolated from the force platform.

2.3 Biomechanical parameters estimation

Following the two sets of squat positions with and without wearing the orthosis, the following parameters were calculated accordingly: the 6 DOF kinematics of the knee joint from the internal landmarks using the biplane images; the flexion/extension of the knee and the trunk inclination using the inertial sensors; the medial and lateral contact point locations; the medial-lateral vector connecting the contact points; ground reaction forces; minimum bone-to-bone distance; location of medial/lateral femoral epicondyle; and the 3D geometry of the bone to check the joint configuration and identifying the orthosis hinge screw location with respect to the joint. The details of the experimental protocol, the 3D/2D registration technique, and the estimation of the contact point location is detailed in Chapter 3 or in A Zeighami et al. (2017).

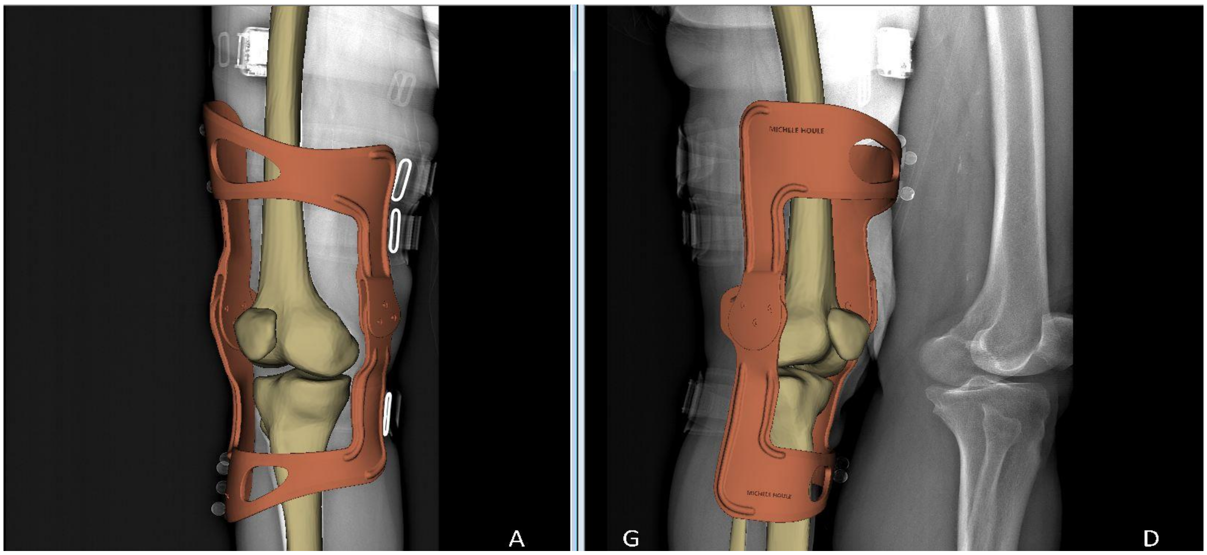


Figure 2: 3D reconstruction of knee while wearing the orthosis under EOS cabinet.

3. RESULTS

The squat postures were controlled and repeated with and without wearing the orthosis using 3 inertial sensors (APDM, inc). The knee flexion angles were maintained in the range of ± 5° from the 5 imposed targeted squat positions i.e. 0°, 15°, 30°, 45°, and 70° knee flexion. Between the two sets of experiments with and without the orthosis, the postures were repeated with an average difference of 2.8° ± 2.3° (maximum error = 5.1°) for the knee flexion and 0.35° ± 3.63° (maximum error = 5.8°) for the trunk inclination.

The kinematics calculated from the internal landmarks (bone-imbedded landmarks) resulted in 10.3±4.1 higher flexion angles compared to those calculated from the inertial sensors. This is reasonable since the internal orientations of the femur and tibia are different from those indicated by the external morphology of the subjects.

3.1 Kinematics under quasi-static squat.

Flexion – Extension angular displacement

In general, the 6 subjects underwent a range of flexion angle from 4.68 deg in standing posture to 82.23 in final squat position without using their orthosis. When using their orthosis the range of flexion angle varies form 4.03 deg to 81.09 deg. We consider then there is no limitation of the flexion angle when using the orthosis (see Table 2).

Table 2: Flexion angle during quasi-static squat movement with and without using the orthosis.

	without orthosis					**with orthosis**				
	0	15	30	45	70	0	15	30	45	70
Flx(+)/ Ext(-) Subject	POS0N	POS1N	POS2N	POS3N	POS4N	POS0W	POS1W	POS2W	POS3W	POS4W
PJ110-01	9,25	44,81	59,88	76,60	83,86	10,54	46,47	56,59	73,57	86,83
PJ110-02	8,06	22,74	37,91	61,09	91,93	5,08	21,38	41,23	53,86	84,01
PJ110-03	8,90	25,90	47,73	57,59	83,99	3,78	20,39	40,76	53,80	80,64
PJ110-04	-1,28	14,47	29,46	39,65	80,10	-2,99	15,11	28,20	38,53	72,90
PJ110-05	1,04	13,34	28,73	44,22	81,63	-0,35	17,64	30,87	48,03	
PJ110-06	2,09	15,50	28,01	40,31	71,90	8,13	17,82	31,26	42,75	
average	4,68	22,79	38,62	53,24	82,23	4,03	23,14	38,15	51,76	81,09
Std	4,60	11,89	12,88	14,56	6,50	5,08	11,65	10,55	12,28	6,02

Adduction – Abduction angular displacement

Table 3 indicate the angular displacement in degree around the adduction-abduction axis. The results show that almost this angle remains almost constant during the controlled quasi-static squat for all of the subjects. In fact in average the adduction angle varies form 3.88 deg from standing posture to 3.91 deg without using the orthosis. Whe using the orthosis, the adduction remains almost the same and varies from 3.62 deg to 3.01 degree. In general we can conclude that the orthosis did not modify the original abduction of the subjects (see Table 3).

Table 3: Adduction (+) – Abduction (-) angular displacement in degrees during quasi-static movement with and without the orthosis.

	without orthosis					with orthosis				
	0	15	30	45	70	0	15	30	45	70
Add(+) /Abd(-) Subject	POS0N	POS1N	POS2N	POS3N	POS4N	POS0W	POS1W	POS2W	POS3W	POS4W
PJ110-01	5,66	2,02	1,23	1,09	1,12	4,67	2,16	1,20	0,37	0,79
PJ110-02	4,42	5,96	5,41	4,80	5,59	4,77	6,06	5,51	5,10	4,69
PJ110-03	1,80	0,14	1,99	0,20	1,08	1,37	2,14	-0,33	-0,85	-0,41
PJ110-04	3,15	4,86	4,70	4,51	7,50	3,03	5,08	4,50	4,71	6,95
PJ110-05	7,06	8,25	8,30	6,68	5,88	6,58	7,94	7,19	7,15	
PJ110-06	1,17	1,69	2,81	2,54	2,27	1,31	1,85	3,43	2,45	
average	3,88	3,82	4,07	3,30	3,91	3,62	4,21	3,59	3,15	3,01
Std	2,27	3,05	2,61	2,46	2,76	2,09	2,54	2,78	3,05	3,42

Internal – External Rotation

There is a high variability in internal external rotation of the knee when using the orthosis and also between subjects. Mainly, all subjects are in internal rotation from the standing to maximal flexion except for subject 5 which had external rotation without using the orthosis. Despite the inter-subject variability, the orthosis induces in average an increase in internal rotation by a value of 6.1 degree for only the two extremes posture i.e standing (0 deg) and maximal flexion (70 deg). However the knee internal rotation angle remains under 1 deg of difference in the other 3 intermediate postures. In average the orthosis had an effect in the standing posture and also in maximal posture. Due to the reduced number of the subjects and their inter-variability caution should be taken to generalize the results to all subjects. We also suspect the original placement the orthosis.

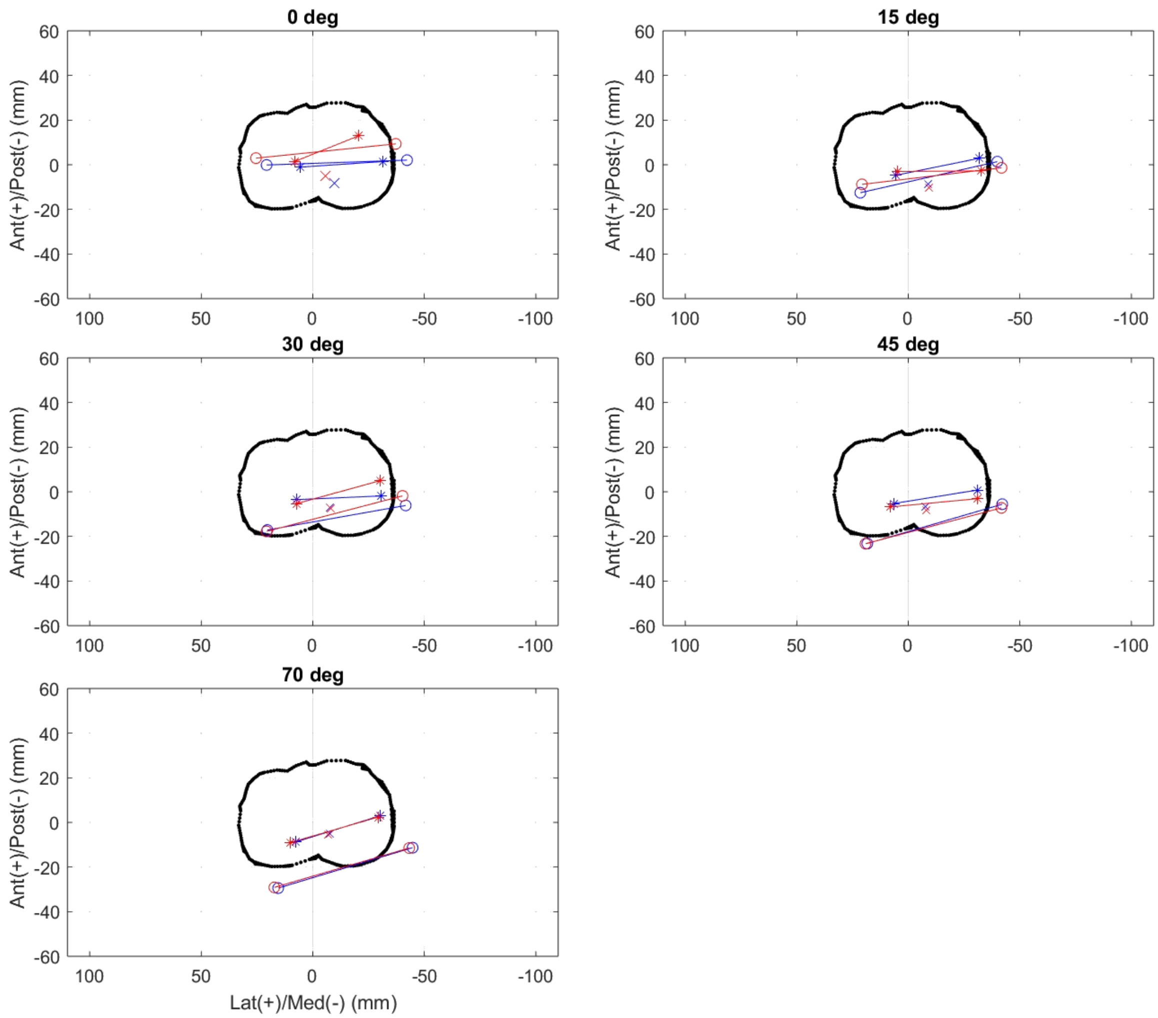
Table 4: Internal (-) – External (+) angular displacement in degrees during quasi-static movement with and without the orthosis.

	without orthosis					with orthosis				
	0	15	30	45	70	0	15	30	45	70
Ext(+)/ Int(-) Subject	POS0N	POS1N	POS2N	POS3N	POS4N	POS0W	POS1W	POS2W	POS3W	POS4W
PJ110-01	-10,46	-19,76	-19,07	-18,07	-17,70	-18,07	-19,62	-19,59	-14,13	-17,51
PJ110-02	-20,52	-49,22	-50,83	-51,07	-52,70	-41,82	-47,68	-47,35	-53,16	-51,67
PJ110-03	-4,13	-15,52	-13,22	-19,44	-19,58	-7,76	-9,35	-17,72	-17,96	-19,19
PJ110-04	-1,92	-10,40	-17,18	-21,73	-18,42	4,69	-12,54	-18,11	-23,08	-22,89
PJ110-05	8,50	1,76	0,81	-6,60	-11,92	2,62	-4,69	-5,23	-7,72	
PJ110-06	-0,16	-8,81	-8,65	-8,48	-8,04	-3,12	-8,96	-6,04	-10,21	
average	-4,78	-16,99	-18,02	-20,90	-21,39	-10,58	-17,14	-19,01	-21,04	-27,82
Std	9,86	17,38	17,57	16,00	15,96	17,34	15,77	15,26	16,66	16,06

3.2. Tibio-femoral contact parameters

During the quasi-static movement, the contact parameters have been defined using geometry congruence between femoral condyle surface and tibial plateau as defined from the reconstructed 3D model by EOS system. A typical subject undergoes a squat movement is represented by figure 3. In fact figure 3 represents the contact point before and after wearing the orthosis.

Figure 3: Location of the medial and lateral contact points (* marks) before (blue) and after (red) wearing the orthosis, the origin of femur (middle of condyles) on the tibia coordinate system (x mark), and the epicondyles projected on the tibial plateau (o marks).



3.2.1 Contact parameters in Anterior (+) and Posterior (-) direction

<u>Medial compartment</u>

The contact parameters are measured generally by the proximity distance between the femoral condyle and tibia plateau. The accuracy of the location of these parameters in medial and lateral compartments, have been estimated in our laboratory in earlier published study by less than 2 mm. The following results include the difference in positioning the contact point parameters in either medial or lateral compartments. In the following, Table 5 shows the AP contact parameters location in the medial compartment. It reveals a different pattern of displacement for each subject. We determined the range of displacement for each subject. It appears that range of displacement of contact parameter varies from 3.26 to 10.06 with an average of 6.59 mm without using the orthosis, whereas this average reach a value of 9.67 mm in anterior direction for the medial compartment. This gives a ratio between the condition with and without about 1.51 (Table 6). This means that the orthosis allowed more range of motion of contact point in AP direction for medial compartment.

Table 5: Contact Parameters (mm) in the condition with and without the orthosis in five postures. Results are for the AP direction in Medial compartment.

	without orthosis					**with orthosis**				
	0	15	30	45	70	0	15	30	45	70
CP\Medial -AP Subject	POS0N	POS1N	POS2N	POS3N	POS4N	POS0W	POS1W	POS2W	POS3W	POS4W
PJ110-01	12,38	13,49	15,05	10,79	5,78	16,63	14,87	16,94	3,49	7,98
PJ110-02	25,62	34,78	27,44	24,72	24,98	34,56	35,16	26,31	28,63	22,66
PJ110-03	1,43	2,88	-1,86	0,76	3,02	12,95	-2,75	4,98	-3,10	2,39
PJ110-04	6,38	5,38	5,41	6,02	3,12	5,19	6,27	5,65	5,08	2,96
PJ110-05	0,35	-4,48	0,05	1,11	-3,50	1,70	0,40	5,46	3,47	
PJ110-06	4,20	0,76	-2,27	-2,03	2,25	2,85	-0,05	-4,40	-1,53	
average	8,39	8,80	7,30	6,89	5,94	12,31	8,98	9,16	6,00	9,00
Std	9,46	14,03	11,81	9,84	9,82	12,38	14,29	10,79	11,53	9,45

Table 6: Range of displacement of contact parameters in AP direction for the medial compartment

	Without	With	Ratio
PJ110-01	9,27	13,45	1,4509
PJ110-02	10,06	12,5	1,2425
PJ110-03	4,88	16,05	3,2889
PJ110-04	3,26	3,31	1,0153
PJ110-05	5,59	5,46	0,9767
PJ110-06	6,47	7,25	1,1206
Average	6,59	9,67	1,52
Std	2,62	5,04	0,89

Lateral compartment

Table 7 exhibits the location of CP (mm) in lateral compartment in the two conditions. In general the two conditions reveal strong similarities that the medial compartment, which mean that range of motion in the lateral compartment, behaves similarly. In fact we have estimate the range of motion of the CP in AP direction for the lateral compartment and the results were that during the squat without the orthosis the average range of motion was about

9.43 mm whereas it stays almost the same when wearing the orthosis i.e. 9.16 mm. This gives a ratio of almost 0.98 which is very close to one. The orthosis did not modify the behaviour of the CP location in the lateral compartment.

Table 7: Contact Parameters (mm) in the condition with and without the orthosis in five postures. Results are for the AP direction in lateral compartment.

	without orthosis					**with orthosis**				
	0	15	30	45	70	0	15	30	45	70
CP\Lateral -AP Subject	POS0N	POS1N	POS2N	POS3N	POS4N	POS0W	POS1W	POS2W	POS3W	POS4W
PJ110-01	1,49	0,58	-6,25	-6,28	-8,85	2,22	0,61	-3,55	-8,61	-7,84
PJ110-02	5,30	2,08	0,10	-5,78	-5,65	3,88	2,62	-1,01	-3,38	-9,43
PJ110-03	-1,07	-4,74	-3,51	-5,28	-8,73	1,53	-3,05	-5,25	-6,78	-8,99
PJ110-04	0,01	-2,42	-5,82	-8,74	-8,57	0,86	-2,74	-6,15	-9,63	-11,11
PJ110-05	1,34	1,82	3,36	0,34	-5,32	2,36	0,91	1,76	0,02	
PJ110-06	0,65	-3,34	-5,95	-4,66	-9,41	-0,76	-4,43	-4,38	-5,94	
average	1,29	-1,00	-3,01	-5,07	-7,75	1,68	-1,02	-3,10	-5,72	-9,34
Std	2,18	2,88	3,94	3,00	1,78	1,57	2,77	2,96	3,56	1,36

3.2.2 Contact parameters in Medial (+) and Lateral (-) direction

Medial compartment

The following text shows the displacement of the contact point in ML direction in the medial compartment of the knee. In general Table 8 shows a very slight reduction (3mm) in reduction on ML displacement of the contact parameters in medial compartment.

Table 8: Contact Parameters (mm) in the condition with and without the orthosis in five postures. Results are for the ML direction in knee medial compartment.

	without orthosis					with orthosis				
	0	15	30	45	70	0	15	30	45	70
CP\Medial -ML Subject	POS0N	POS1N	POS2N	POS3N	POS4N	POS0W	POS1W	POS2W	POS3W	POS4W
PJ110-01	36,40	34,99	28,81	27,59	25,89	35,02	33,38	31,23	26,82	22,24
PJ110-02	24,30	15,47	23,12	20,45	19,08	20,41	16,08	22,89	19,01	18,24
PJ110-03	31,33	31,67	30,78	30,87	30,37	20,58	32,53	30,22	30,87	29,26
PJ110-04	21,13	27,35	25,76	25,61	21,82	18,09	27,65	25,82	24,55	21,98
PJ110-05	26,50	24,88	14,12	25,32	19,64	23,42	26,84	24,48	25,00	
PJ110-06	10,76	22,74	23,80	24,73	15,63	14,66	19,48	26,30	23,92	
average	25,07	26,18	24,40	25,76	22,07	22,03	25,99	26,82	25,03	22,93
Std	8,84	6,89	5,82	3,43	5,29	7,00	6,95	3,26	3,88	4,60

Lateral compartment

Table 9 presents the result of the displacement of contact parameters in ML direction for knee lateral compartment. Even if the average of the group of six subjects seems similar between the two conditions, it appears a sort of lateralization of the CP in lateral compartment towards a lateral direction. This lateralization appears sometimes more effective for Pos3 and Pos4.

Table 9: Contact Parameters (mm) in the condition with and without the orthosis in five postures. Results are for the ML direction in knee lateral compartment.

	without orthosis					with orthosis				
	0	15	30	45	70	0	15	30	45	70
CP\Lateral-ML Subject	POS0N	POS1N	POS2N	POS3N	POS4N	POS0W	POS1W	POS2W	POS3W	POS4W
PJ110-01	-5,90	-5,86	-16,67	-13,60	-16,96	-6,07	-6,79	-13,06	-19,62	-17,51
PJ110-02	-9,12	-5,03	-2,62	-7,45	-5,97	-4,79	-5,69	-6,21	-5,79	-11,68
PJ110-03	-5,44	-5,66	-7,14	-6,62	-7,55	-7,92	-4,92	-7,07	-7,98	-9,88
PJ110-04	-6,52	-5,43	-5,83	-5,23	-7,62	-6,94	-5,27	-5,82	-5,47	-7,00
PJ110-05	-6,32	-7,41	-17,16	-10,05	-20,01	-6,78	-6,94	-9,59	-11,18	
PJ110-06	-6,72	-7,30	-13,51	-9,69	-19,81	-6,80	-8,66	-8,30	-11,39	
average	-6,67	-6,11	-10,49	-8,77	-12,99	-6,55	-6,38	-8,34	-10,24	-11,52
Std	1,29	1,00	6,11	2,99	6,62	1,05	1,38	2,70	5,25	4,43

3.2.2 Excursion in Contact Point Parameters

During our analysis, we found a clear pattern of excursion of the CP parameters in the anterior-posterior direction. Table 10 presents the mechanism of this excursion: it represents the anterior-posterior excursion of the contact points and the ratio of the medial to lateral excursion with and without wearing the orthosis. Here, the excursion is defined as the distance (in anterior-posterior direction) between the two farthest contact points during the quasi-static squat. The ratio of the medial to lateral excursions is greater after wearing the orthosis. This suggests that the orthosis is inducing lateral pivot kinematics to the joint. Recent studies in knee kinematics during gait have found a lateral pivot in healthy knee. In this sense the effect of the orthosis could be considered here as beneficial. Table 11 represents the same computation as the in Table 10 but for the medial-lateral direction. It represents a mixed pattern for example subject P004 (Table 11) has an excursion in ML axis in medial compartment of 6.22 mm without orthosis and this increases to 9.56 mm with the orthosis. In the same time the excursion decreased from 2.39 mm to 1.73 mm for the lateral compartment correspondingly. So the use of the orthosis reduced the excusion in lateral compartment and increased it the medial compartment which gave a high ratio of 5.52. This is explain a higher internal rotation for this subjects. Mainly speaking there is an effect of the orthosis in the AP and ML direction. The pattern in AP direction is less complex than the one in ML direction.

Table 10: Anterior-posterior (mm) excursion of the contact points and the ratio of the medial to lateral excursion with and without wearing the orthosis

	without	with	without	with	without	with
	medial compartment excursion		lateral compartment excursion		ratio of med/lat excursion	
P001	9,27	13,45	10,34	10,84	0,90	1,24
P002	10,05	12,50	11,08	13,31	0,91	0,94
P003	4,88	16,06	7,66	10,53	0,64	1,53
P004	3,26	3,32	8,75	11,96	0,37	0,28
P005	5,58	5,06	8,68	2,35	0,64	2,16
P006	6,47	7,25	10,05	5,18	0,64	1,40

Table 11: Medial – Lateral (mm) excursion of the contact points and the ratio of the medial to lateral excursion with and without wearing the orthosis

	without	with	without	with	without	with
	medial compartment excursion		lateral compartment excursion		ratio of med/lat excursion	
P001	10,51	12,78	11,10	13,55	0,95	0,94
P002	8,83	6,81	6,50	6,89	1,36	0,99
P003	1,29	11,95	2,11	4,96	0,61	2,41
P004	6,22	9,56	2,39	1,73	2,60	5,52
P005	12,38	3,42	13,69	4,40	0,90	0,78
P006	13,96	11,64	13,09	4,59	1,07	2,53

3.3 Ground reaction forces

The ground reaction forces under the ipsilateral foot have been measured using accurate force platform under EOS cabinet. Here we present these unique results since there no comparative data in literature. Table 12 reveals that in standing position the effect of wearing the orthosis is to put more weight on the instrumented limb, which means that the subjects in average are more confident to load their ipsilateral knee in posture POS0 and POS1. Since the movement of squat is a not an automatized movement, variability exist from the 30 to 70 deg of flexion.

Table 12: Resultant of ground reaction forces

	without orthosis					**with orthosis**				
	0	15	30	45	70	0	15	30	45	70
GRF - Res	POS0N	POS1N	POS2N	POS3N	POS4N	POS0W	POS1W	POS2W	POS3W	POS4W
Subject										
PJ110-01	559,98	321,20	410,01	232,38	237,90	556,68	413,46	300,29	272,66	214,00
PJ110-02	377,74	368,63	270,35	309,77	286,36	365,14	430,34	354,05	317,79	319,75
PJ110-03	433,47	491,33	463,08	368,95	320,95	489,58	509,71	502,82	456,27	282,32
PJ110-04	628,19	604,21	698,69	652,89	306,57	700,16	653,32	566,49	651,45	361,68
PJ110-05	462,84	454,57	413,22	366,68	244,29	482,10	448,28	380,54	324,12	
PJ110-06	384,60	527,93	438,20	402,18	383,50	485,43	444,94	426,44	445,22	
average	474,47	461,31	448,92	388,81	296,60	513,18	483,34	421,77	411,25	294,44
Std	100,19	103,95	139,55	142,49	53,91	110,51	89,42	98,57	138,86	62,66

CONCLUSION

This project was dedicated to a proof of concept for the use of 3D/2D registration techniques to investigate the effect of a valgus knee orthosis on the knee kinematics and contact point locations. The contact point locations of the subject in this study did not demonstrate a shift after wearing the orthosis.

Comparing the contact point location with and without the orthosis requires accurately repeating the posture in the two set of experiments to minimize the effect of posture differences on the contact point locations. Inertial sensors provided a repeatable means of controlling and adjusting the posture in real-time. The sensors attached to skin are not necessarily aligned with the bone causing a bias in the flexion/extension estimations. That is why a calibration was necessary to control the subject posture in the EOS cabinet.

Each orthosis is designed according to the anatomical landmarks which are estimated from the digitized skin surface of the subject. The extent to which these estimated points correspond to the real anatomical landmarks requires knowledge of the skeleton configuration with respect to the orthosis. Using the 3D/2D imaging techniques for the analysis of the orthoses allows accurate localization of the orthosis with respect to the skeleton and the joint. Having the orthosis and the skeleton in one frame during movement is of high interest and importance in the design of the orthoses. This could also help to verify if the orthosis is placed as expected with respect to the joint and if desired design kinematics (e.g., that of (P. Walker et al., 1985)) is reproduced.

This study showed the feasibility of testing the impact of a knee orthosis on the kinematics, ground reaction forces, and contact points using 3D/2D registration techniques. However, it is not clear if the observed changes exist in the other subjects and if wearing the orthosis affects them in the same direction/manner. In kinematics the internal rotation of the knee is affected as well as contact parameters also in medial and lateral compartment. Data on ground reaction forces slightly changes in terms of loading more the intrumented knee. We can briefly conclude that the data provided here concur to the beneficial use of the knee orthosis.

Annexe -1

General Results

Figure A-1 displays the average trajectory of 6 subjects (in red and blue star). The average trajectory was superimposed with the OA database of LIO in yellow circle and healthy persons in green circle.

Lateral compartment:

In the lateral compartment, the trajectory of the without orthosis is close to the OA subjects however it deviates for higher flexion angle. The red trajectory which corresponds to the use of the orthosis is more linear than the blue one but remains close to OA subjects.

Medial compartment

In media compartment, although the red and blue trajectory remains close to the one of OA, there is a difference in that the orthosis push the trajectory in lateral direction for P0 and P4 and remains at the middle between the OA and Healthy subjects. It should remain that this is average trajectory, individual trajectories are very specific and subject dependent as shown in the next section

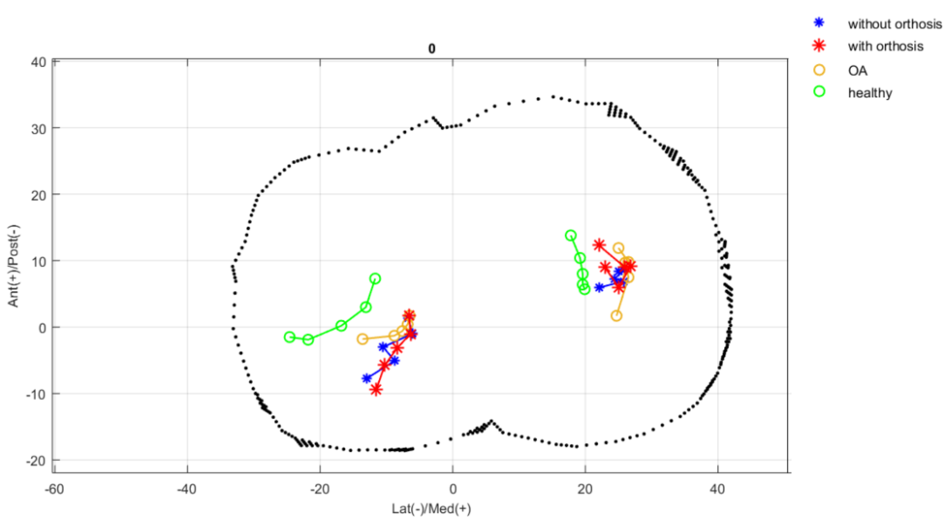
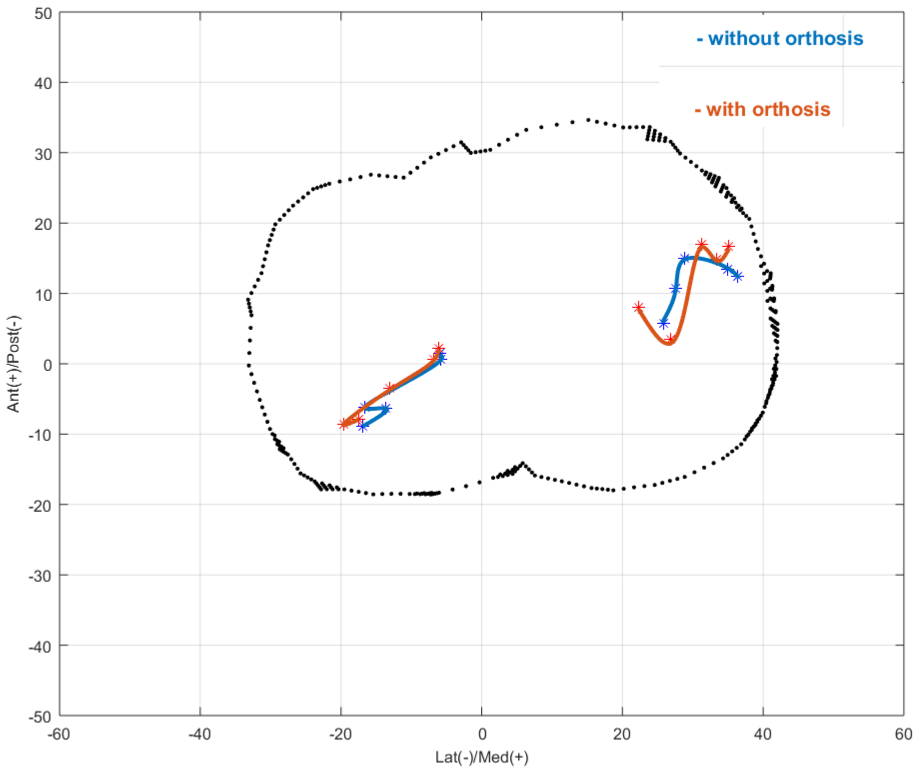


Figure A-1 : Graphical display of the average (6) subjects superimposed with the database of Zeighami et al. (2017).

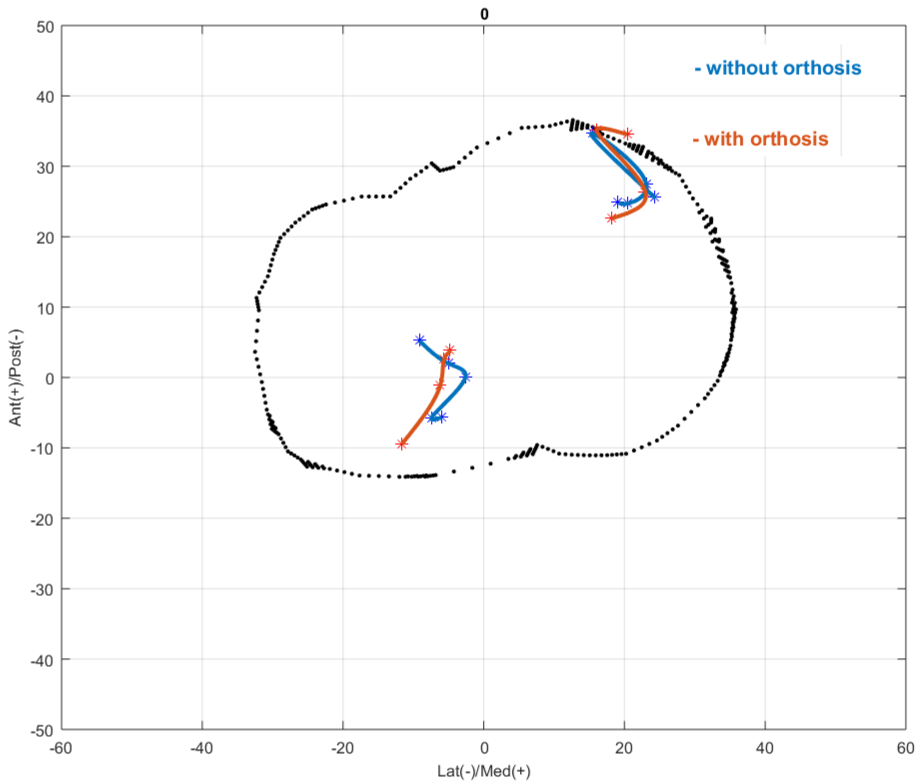
Individual Results.

The flowing section presents the individuals results of each subject.

Subject-1

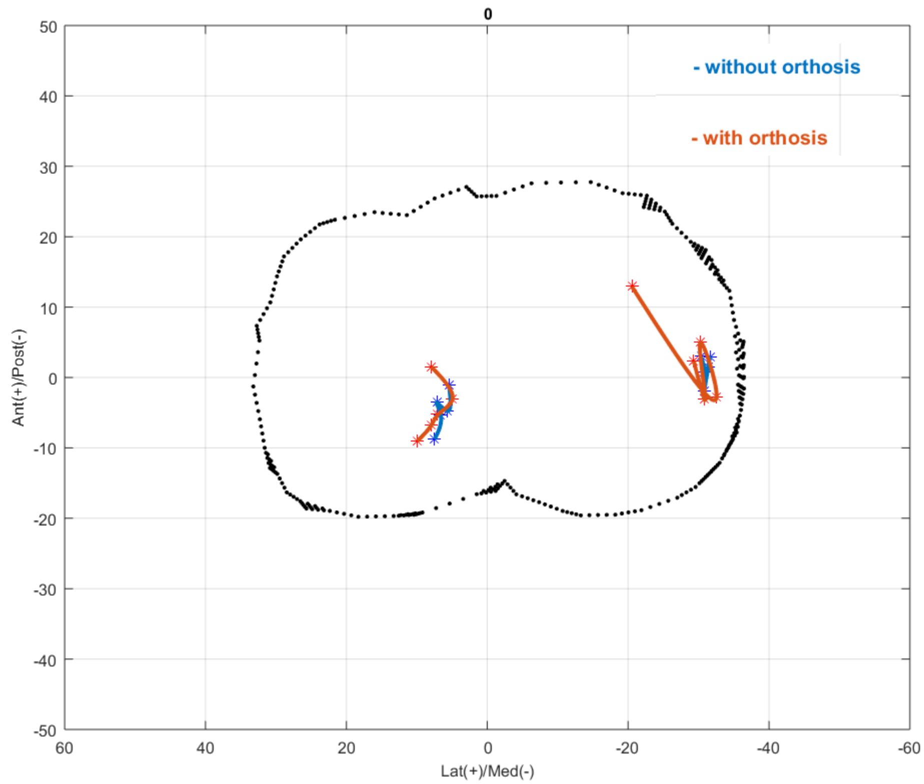


Subject-2



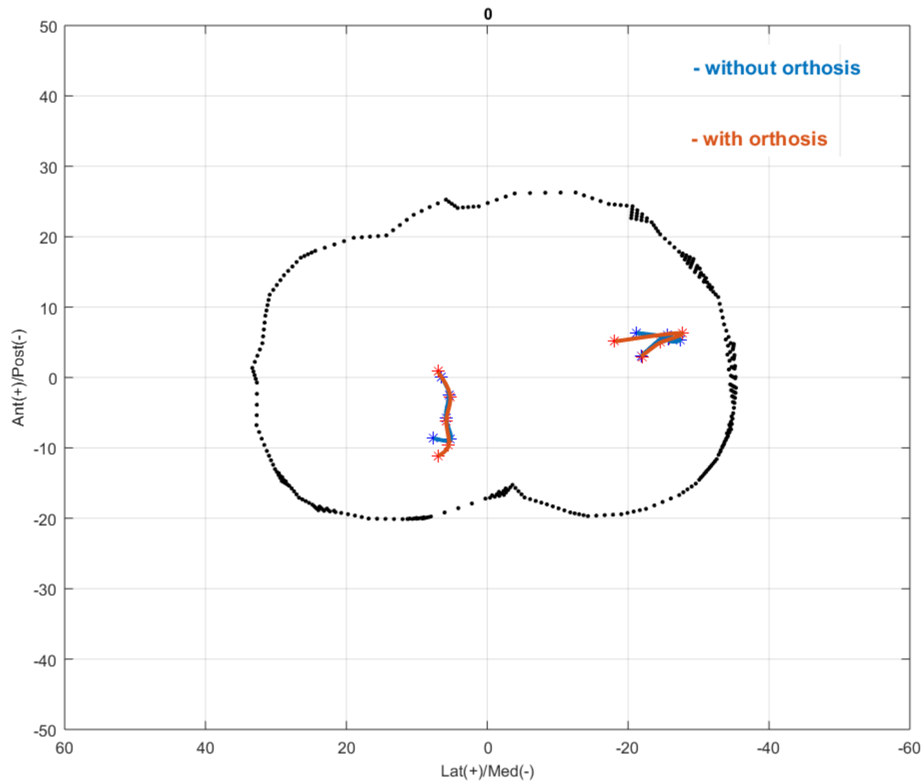
0
- without orthosis
- with orthosis
Ant(+)/Post(-)
Lat(-)/Med(+)
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-40
-20
0
20
40
60

Subject-3

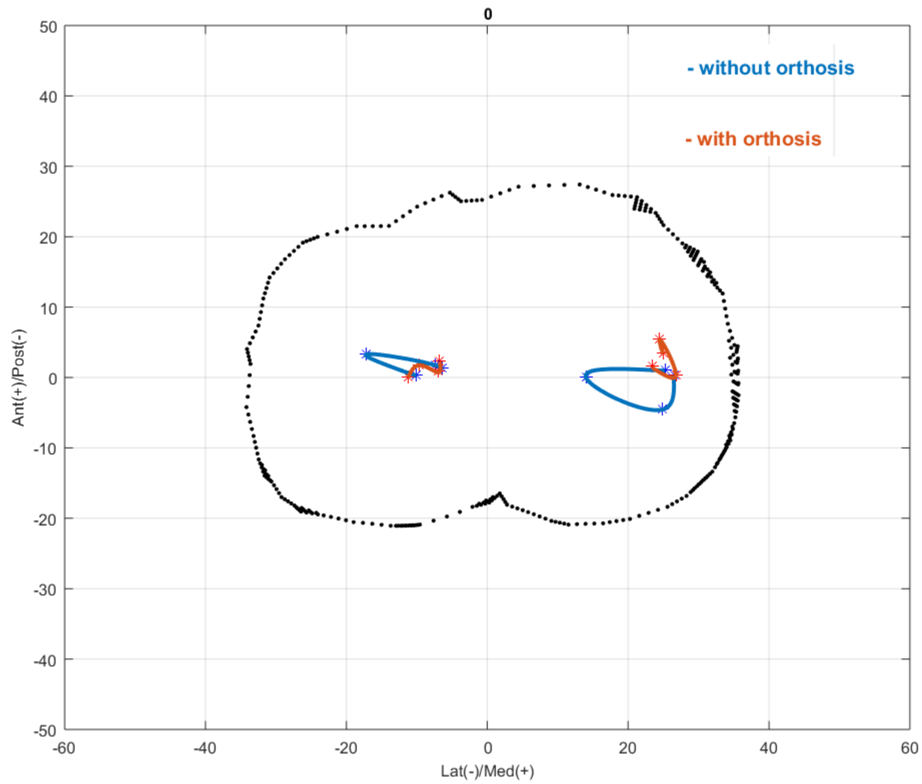


0
- without orthosis
- with orthosis
Ant(+)/Post(-)
Lat(+)/Med(-)
50
40
30
20
10
0
-10
-20
-30
-40
-50
60
40
20
0
-20
-40
-60

Subject-4

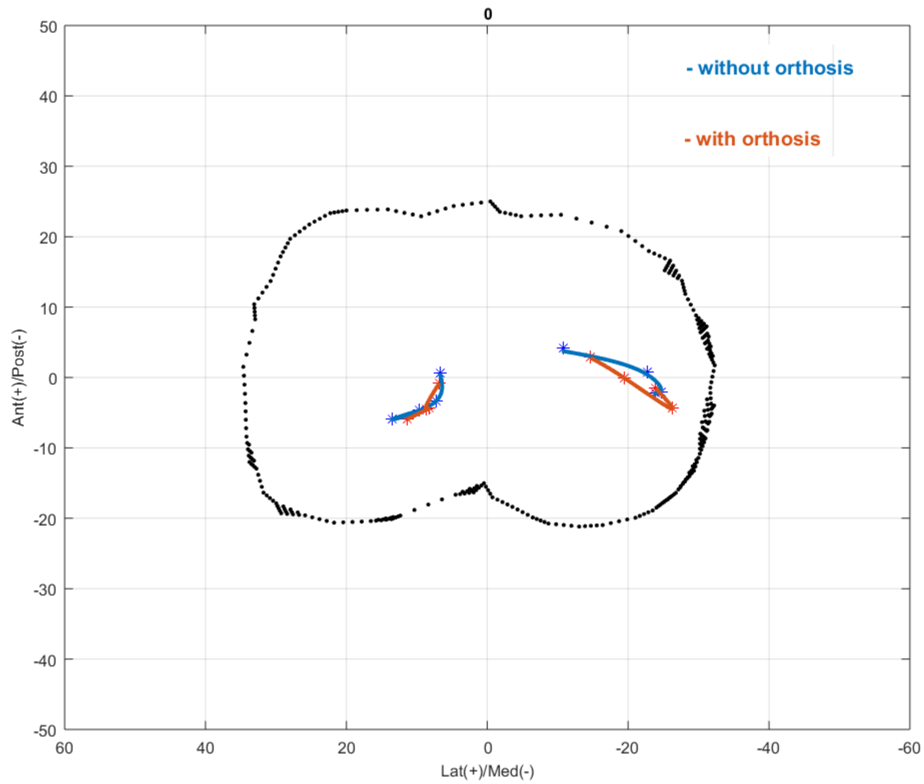

0
- without orthosis
- with orthosis
Ant(+)/Post(-)
Lat(+)/Med(-)
50
40
30
20
10
0
-10
-20
-30
-40
-50
60
40
20
0
-20
-40
-60

Subject-5



0
- without orthosis
- with orthosis
Ant(+)/Post(-)
Lat(-)/Med(+)
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-40
-20
0
20
40
60

Subject-6


0
- without orthosis
- with orthosis
50
40
30
20
10
0
-10
-20
-30
-40
-50
60
40
20
0
-20
-40
-60
Ant(+)/Post(-)
Lat(+)/Med(-)