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

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Abstract

This project was performed in the framework of an industrial collaboration with the Medicus company. The aim of the project was to assess the new orthosis recently developed by Medicus Company. The general investigation was to compare kinematics ground reaction forces and bone-to-bone distance at the contact point locations in OA subjects during a quasi-static task with and without wearing a knee orthosis in a multiple squat postures. Our hypothesis was that the knee orthosis influences the unloading aspect at the tibiofemoral contact point locations in OA subjects by enhancing the bone-to-bone distance in medial and lateral compartment. Also the knee orthosis will not alter the normal kinematics induced by the screw-home mechanisms of the Evoke orthosis. Also we will investigate the possible shift of theses point contacts. 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 during a controlled squat movement using biplanar low dose x-ray (EOS).

2. METHODS

2.1 Subjects

Sixteen subjects (N=16) 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
(subject 7 was excluded due to incomplete data)

ID	Date	Age	Gender	Weight	Height	side
1	2017-07-05	62	M	194lb	1.77 m	R
2	2017-07-26	73	F	145lbs	1.60 m	R
3	2017-06-28	68	F	198lbs	1.70 m	L
4	2017-07-03	55	F	280lbs	1.79 m	L
5		54	F	176lbs	1.57 m	R
6	2017-06-19	77	F	190lbs	1.55 m	R
7	2017-07-06	59	M	245lbs	1.78 m	R
8	11.03.2019	64	M	100Kg	1.80 m	L
9	24.05.2019	50	F	57 Kg	1.62 m	L
10	19.03.19 D et 03.05.19 G	33	F	85Kg	1.68 m	R
11	04.04.2019	54	F	84 Kg	1.65 m	L
12	21.06.2019	68	F	57Kg	1.68 m	L
13	21.06.2019	82	F	58Kg	1.56 m	R
14	25.06.2019	64	M	106Kg	1.80 m	L
15	17.07.2019	41	F	73Kg	1.63 m	R
16	26.07.2019	42	M	109Kg	1.83 m	R

A personalized Evoke orthosis was fabricated for each participant at Médicus laboratory. At least one month adaptation period is required for wearing the orthosis before doing the test.. Clinical evaluation was made by Dr. Lavoie Frederic from the orthopedic department at the CHUM. 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° i.e. at 0°, 15°, 30°, 45°, and 70° 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 low dose x-ray biplane images was acquired. To ensure that the posture is the same with and without the orthosis, 3 inertial (APDM sensors or Noraxon Sensors) were placed at the level of sagittal part of the shank, the thigh, and at the frontal part of the 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 until the predefined posture was reached.

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 were maintained at the same level (Fig. 1). The spacing between the feet was defined so that the distance between the external malleoli corresponds approximatively to the inter-acromion distance 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

During the acquisition of the ten postures, a specific method for the semi-automatic segmentation of the lower limb segment i.e. the tibia and the femur was based on multiple-view process using the Idefix software at the LIO. All of the 10 postures were used to reconstruct the 3D model of the femur and tibia bone and orient it with respect to each of the 10 postures. This procedure take a fastidious time for each subjects. In this case, we assure that high precision of the whole skeletal reconstruction. 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 vertical ground reactions forces; the minimum bone-to-bone distance in medial and lateral compartment; 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 Zeighami et al. (2017).

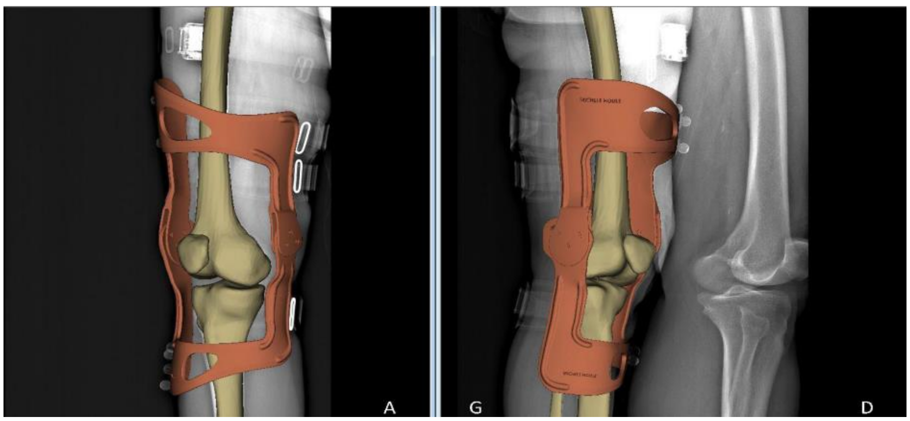

Figure 2: 3D reconstruction of knee while wearing the orthosis under EOS cabinet for typical subject.

The statistical approach used in this study was the analysis of variance for the dependent variables i.e. tibio-femoral contact parameters (CP): the location of CP and bone-to-bone distance in medial and lateral compartments.

3. RESULTS

3.1 Postural control during the acquisition of EOS imaging

During data collect, the squat posture was controlled by real-time monitoring of the trunk flexion and the knee flexion angular displacement using inertial sensors.

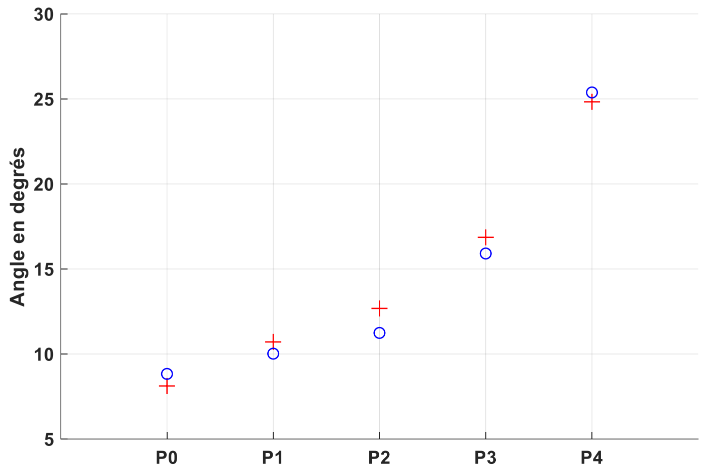

Figure 3. Average (N=15) trunk flexion angle during the acquisition in EOS. P0 to P4 correspond to 0, 15, 30, 45 & 70 deg knee flexion. (+) with orthosis; (o) without orthosis

Figure 3 exhibits the trunk flexion of the subject inside the EOS cabinet during the five postures as adopted by the subjects. We can consider from the results that the entire subject adopted the same trunk orientation in sagittal plane during the five imposed knee flexion angles. Between the two sets of experiments with and without the orthosis, the postures were repeatable and varied from 8 to 25 degrees in trunk flexion. Figure 4 shows, the knee flexion extension of the subjects when asked to adopt the 5 postures with and without the orthosis. We should not here the control of the repeatability of the subject during the acquisition. However we should note also that most of the subjects did not reach the extreme position P4 since the average is about 64 degrees flexion using the jig to maintain Their stability. In fact, for each posture the subject should stay in quiet position at least 20 seconds: this is the necessary time for the biplane images to be taken. It should be noted that the knee flexion are based on a calibration procedure of the inertial sensor which indicates the knee flexion angle base on the external morphology of each subjects. The flexion angle between the internal bones (tibia and femur) will be described in the next section.

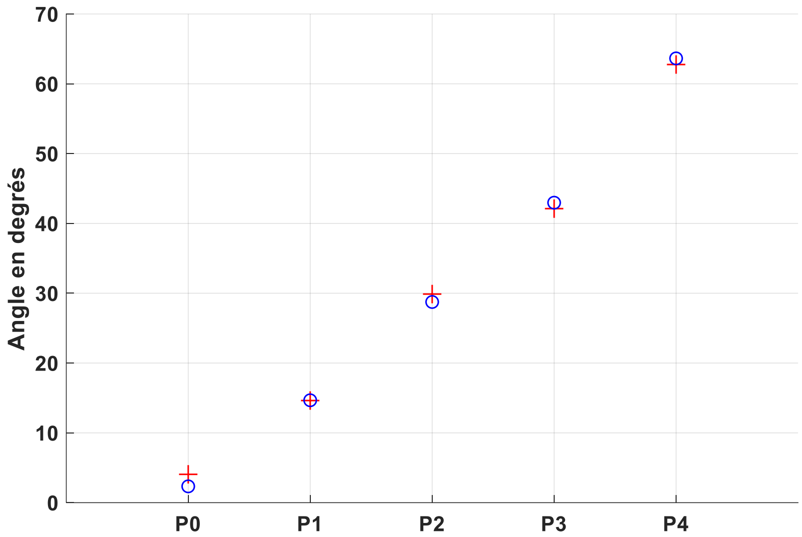

Figure 4: Average (N=15) knee flexion angle during the acquisition in EOS. P0 to P4 correspond to 0, 15, 30, 45 & 70 deg knee flexion. (+) with orthosis; (o) without orthosis.

3.2 Tibio-femoral contact parameters during quasi-static squat

Two parameters have been estimated during this study the bone-to-bone distance, and the position of the contact parameters with respect to the tibial plateau. For each point on the tibial plateau, the minimal point-to-point distances to the opposing medial or lateral condyles were calculated at the 5 squat positions. A weighted center of proximity algorithm was performed to find a point on each plateau that most likely represented the contact parameters (CP). The corresponding points on the opposing femoral condyles represented CPs of the femur and the calculated distances were assumed to represent minimum tibio-femoral bone-to-bone distances. Since in the proposed reconstruction technique, the personalized bones were deformed versions of generic model bones, a unique correspondence existed between each point on the generic bone and its deformed versions, such that vertices located on any anatomical landmarks (e.g., lateral intercondylar tubercle) correspond to the same landmark after deformation. These correspondences allowed a feature-based normalization to represent the calculated CPs positions of all subjects, on a right tibial plateau with 74 mm medial/lateral width. The accuracy of the estimated bone-to-bone distance have been estimated to 0.8 mm rms error, whereas the position in anterior-posterior and medial-lateral direction have an estimated rms error of 2 mm and 3 mm respectively.

3.2.1 Bone to bone distances.

The bone to bone distance have been estimated during the 5 postures from P0 to P4. The bone-to-bone distance represents a surrogate of the unloading process.

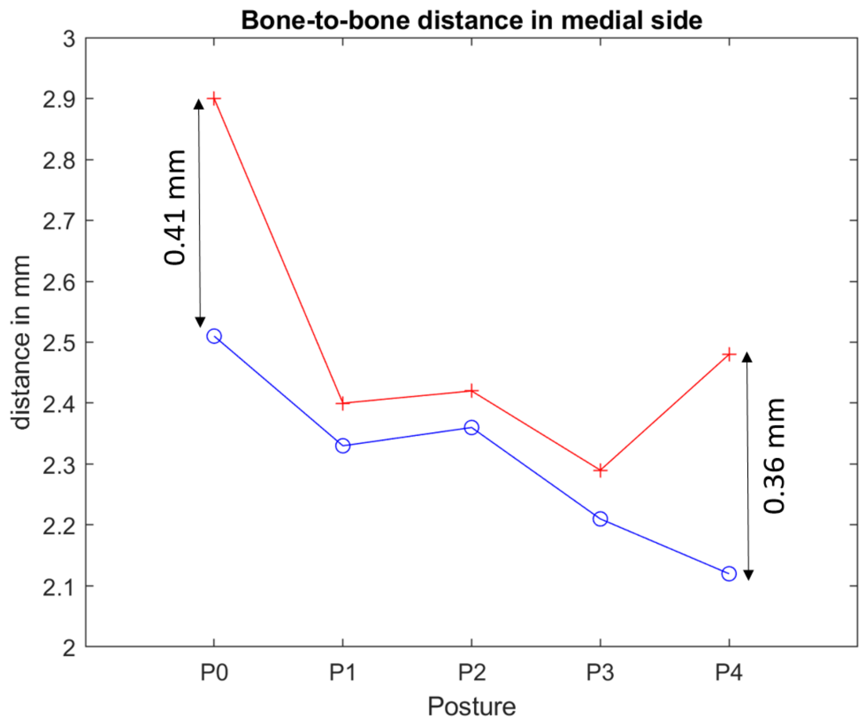

Figure 5: Average (N=13) bone-to-bone distance (mm) in the medial compartment for five postures P0, P5. (red +) using the orthosis; (blue o) without an orthosis.

Figure 5 shows the average variation of the bone-to-bone distance from the standing position P0 which represents an increase of the distance by 0.41 mm in average and an increase for the extreme squat posture of 0.36 mm. However, the statistical two-way analysis of variance (posture x orthosis) did not reach a significant effect due to the high variability of the subject. In fact, Table 2 indicate a positive augmentation of the bone-to-bone distance in the medial compartment which varies from 17.7 % in P0 to reaches 44.1% in P3.

Commented [PC1]: Est-ce que l'on peut aussi vérifier les résultats si on enlève les extrêmes?

Table 2: Percentage (%) of augmentation (positive) and a decrease (negative) of the bone-to-bone distance in medial compartment for the 15 subjects.

P0	P1	P2	P3	P4
-18,58	65,71	-18,21	-12,90	10,62
63,35	-17,29	1,89	-6,15	36,33
41,28	-27,78	83,68	-16,29	
41,82	3,67	-35,45	34,35	-51,03
6,64	5,30	-11,51	-9,09	
6,31	23,33	-19,55	-31,44	
-7,98	-5,28	-58,94	603,77	33,88
52,90	-12,21	-27,31	43,10	-8,49
20,91	18,96	-10,24	11,64	-31,48
-16,32	-30,86	-22,70	-21,57	41,59
-15,71	-24,66	119,12	-8,46	73,43
3,79	0,80	5,00	53,10	-6,09

55,08	22,81	31,07	5,00	95,76
19,42	-27,11	17,37	6,71	21,41
12,78	-0,04	44,41	9,84	-21,65
17,71	-0,31	6,58	44,11	16,19

To compare with the literature we found one important study maid by the team of Denis et al. (2006) which evaluate the effect of six unloading braces namely (Bledsoe, DJ Ortho, Breg, Isports, Gen II, ACL). In this earlier study, the authors first used a 2D fluoroscopic imaging technique to measure the bone-to-bone distance during treadmill walking. Table 3 reveals the data gathered in this study. Since we are dealing with static postures, we compare our data to the midstance event during gait where the lower limb is almost aligned vertically. We can locate the Evoke orthosis at the high level with respect to the Bledsoe: our data reaches 2.9 mm with the Evoke whereas the Bledsoe never exceed 1.3 mm. It should be noted here that the bone-to-bone distance is measured with respect to the 2D plane of the fluoroscopic images and could induce a discrepancies of the parameters due to the inaccuracy of the fluoroscopic images.

Table 3: Absolute data on bone-to-bone distance extracted from Dennis et al. (2006). The value represent the average of 45 subjects. The red arrow indicate the level of Evoke orthosis

Brace type	Heel strike	Midstance	Toe-off
Bledsoe	1.3 (0-2.3), SD = 1.1	0.6 (0-1.6), SD = 0.8	1.3 (0-1.7), SD = 1.0
DJ Ortho	1.2 (0-2.4), SD = 1.3	0.3 (0-1.0), SD = 0.5	0.4 (0-0.8), SD = 0.8
Breg	0.7 (0-2.7), SD = 1.2	0.1 (0-1.3), SD = 0.7	0.2 (0-0.7), SD = 0.4
Isports	0.7 (0-2.1), SD = 1.0	0.0 (0-0.8), SD = 0.5	0.0 (0-0.2), SD = 0.2
Gen II	0.7 (0-3.4), SD = 1.6	0.2 (0-1.3), SD = 0.8	0.1 (0-0.9), SD = 0.5
ACL	0.2 (0-0.4), SD = 0.3	0.0 (0-0.3), SD = 0.2	0.0 (0-0.3), SD = 0.3

Furthermore, and in the same study of Denis et al. (2006), the authors asked five patients to wear six orthosis, and they develop a CT-scan 3D model of their knee whereas they measure the bone-to-bone distance in the medial compartment with respect to the baseline i.e. without wearing the orthosis. Table 4 shows their results for five (5) subjects.

Table 4: Average bone-to-bone distance difference in mm between wearing and no-wearing the orthosis during treadmill gait. (Dennis et al., 2006).

Subject	Bledsoe	DJ Ortho	Breg	Isports	Gen II	ACL
Subject 1	0.9	0.4	0.3	0.2	0.2	0.1
Subject 2	0.6	0.4	0.5	0.0	0.0	0.1
Subject 3	0.8	1.0	0.4	0.0	0.0	0.2
Subject 4	0.1	0.0	0.1	0.0	0.0	0.0
Subject 5	1.6	0.8	0.9	0.5	1.0	0.1
Average	0.8	0.5	0.4	0.2	0.2	0.1

The maximal average value indicated in table 4 is 0.8 mm for the Bledsoe. We have selected the best 5 subjects from our group and the results shows a value of 0.92 mm which is better than the Bledsoe orthosis. It should be noted that Dennis et al. (2006) found also that 60% of their subjects (N=45) reached a distance of 0.3 mm when using the Bledsoe. We found in our study (N=15) that in standing posture 100% of our subjects exceeded 0.3 mm. In fact the bone-to-bone distance varies from 0.55 to 5.59 mm for the posture P0.

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The bone-to-bone distances were analyzed also in the lateral compartment. Figure 6 shows the variation of the bone-to-bone distance in lateral compartment. The bone-to-bone distance in lateral compartment is larger than the one measured in the medial compartment. The two-way analysis of variance reveals a significant effect between posture P2 and P3 and the rest of the other postures. However, the statistical comparison between the condition of wearing or not the orthosis did not reach a significant effect for the lateral compartment. However, there are trends similar to the medial compartment i.e. an effect in P0 and P4 postures.

Research and study are scares in literature to find a comparative data for the lateral compartment. Table 5 shows the percentage of the increase in bone-to-bone distance in lateral compartment which varies from 45.9% for P1 to 2.20% for P3 with respect to the baseline i.e. without wearing the orthosis. This demonstrated that in fact there are unloading situations which happened in the lateral compartment. It should be noted that the lateral compartment bears also a non-negligible amount of load during the stance phase of the gait (Zeighami et al., 2021)

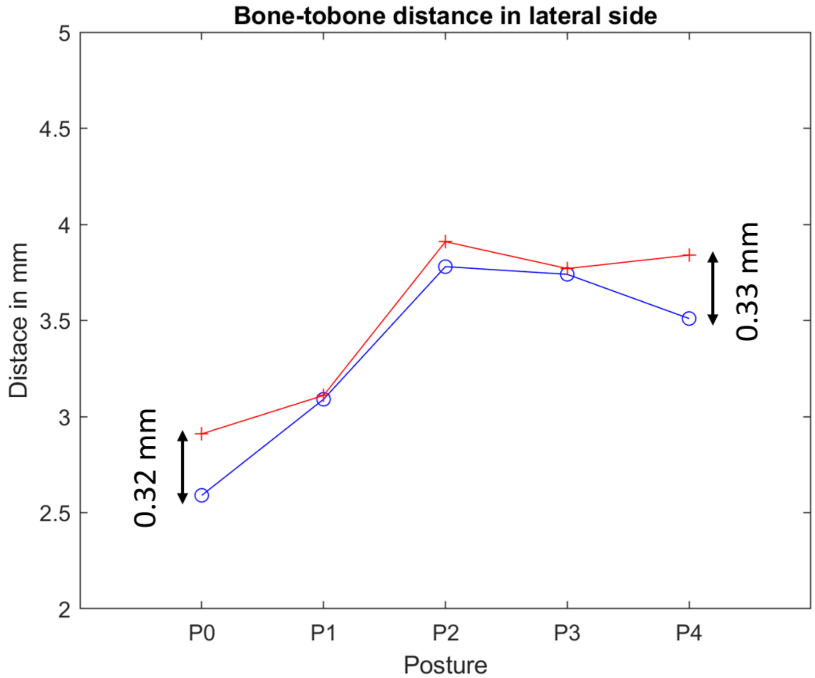

Figure 6: Average (N=13) bone-to-bone distance (mm) in the lateral compartment for five postures P0, P5. (red +) using the orthosis; (blue o) without an orthosis.

Table 5 Percentage (%) of augmentation (positive) and a decrease (negative) of the bone-to-bone distance in lateral compartment for the 15 subjects.

P0	P1	P2	P3	P4

-26,85	19,52	-3,17	-39,39	8,25
2,96	-5,32	20,76	-7,47	0,96
571,16	32,45	4,78	-43,54	55,90
13,81	28,21	19,78	10,10	4,67
-2,89	-23,86	-42,95	24,94	0,00
-4,09	16,75	-18,38	5,11	0,00
53,14	-3,63	35,78	-12,03	2,77
-12,49	5,97	-4,82	-12,41	3,16
17,13	14,03	10,48	-8,92	3,17
-16,70	9,27	9,87	51,54	16,67
27,11	6,15	23,87	10,30	11,30
-15,48	15,45	10,00	15,17	-3,92
54,01	-16,77	-26,61	13,14	12,15
14,87	-16,14	20,20	9,17	7,87
12,91	-11,15	27,61	17,23	1,40
45,91	4,73	5,81	2,20	8,29

3.2.2 Tibio-femoral contact points positions parameters

During the quasi-static movement, the contact location parameters are represented by two parameters: i) the projection of the origin of the distal part of the femur is projected onto the tibial plateau origin (Fig. 7); ii) and the displacement of the contact parameters in the

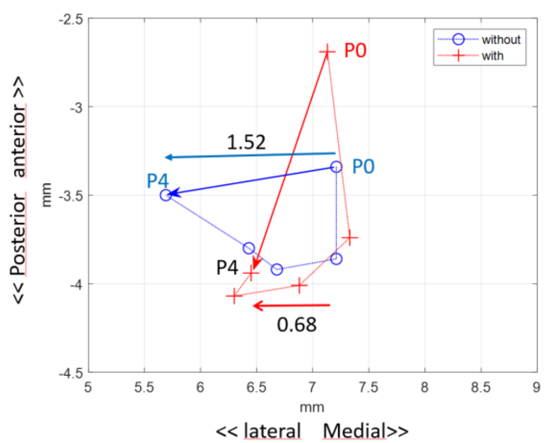

Figure 7: Average projection of femoral origin on tibial plateau

Lateral and medial compartment (figure 8). Figure 7 exhibits the trajectory of the origin during squat movement. Using the evoke orthosis, the displacement of the origin of the femur exhibit greater displacement in A/P direction than without, whereas it limited the medial-lateral displacement.

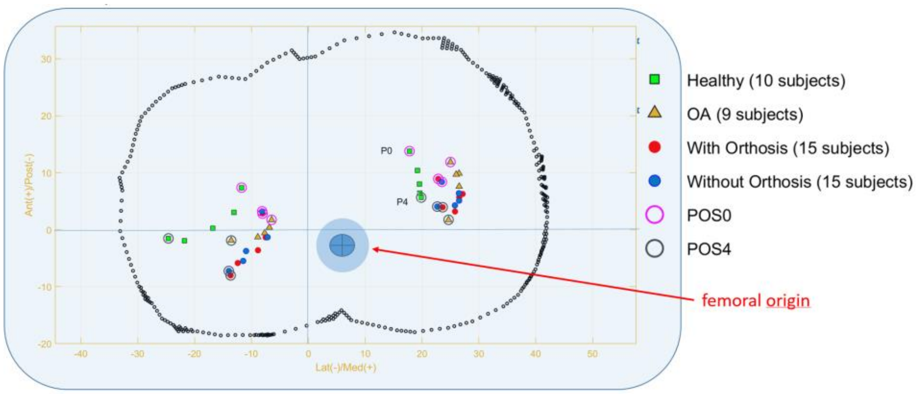

Figure 8: Representation of three groups of population Healthy, Osteoarthritis subjects as well as group (N=15 subjects).

In figure 8 we superimpose the results of actual study with our earlier database formed by 10 healthy elderly and 10 patients with osteoarthritis (grade 4) which undergoes the same protocol i.e. a 5 squat postures in EOS imaging (Zeighami et al., 2017). It should be noted that when using the Evoke orthosis the subjects contact parameters are located in between the pathological subjects and the able-bodied one for posture P0 and P4 only. This means that the effectiveness of lateralization exist for the Evoke orthosis.

Commented [PC3]: Connaissons nous l'effet des autres qui semble se diriger vers l'avant ou l'arrière, on ne peut possiblement pas dire qu'il n'y a pas d'effet mais moins visible dans les autres positions

Commented [PC4]: Peux tu nous indiquer clairement le montant en moyen qu'on lateralise (en mm) avec l'orthese Evoke. Ou autres façons de quantifié le laterisation.

3.3 Pseudo kinematics during squat movement

The pseudo-kinematics during squats movement was measured using the International Society of Biomechanics standard, which is defined by the independent sequence of Euler angle following the method of Groot & Suntay (1983). Figure 9 shows the origin of femur (Of): midpoint of 2 spheres fitted on the posterior femoral condyles. The proximal/distal axis of femur (Yf), while Of is the center of the femoral head. The Zc axis connecting the centers of the posterior condyles. The anterior/posterior axis of femur (Xf) is the cross product of Yf and Zc, oriented anteriorly. The medial/lateral axis of femur (Zf) is obtained by the cross product of Xf and Yf. The origin of tibia (Ot) is the center of intercondylar eminence. The proximal/distal axis of tibia (Yt) is midpoint of the medial and lateral malleoli Ot. The Zp axis is passing through the posterior extremes of the tibial plateaus. The anterior/ posterior axis of tibia (Xt) corresponds to the cross product of Yt and Zp, oriented anteriorly. The medial/lateral axis of tibia (Zt) is the cross product of Xt and Yt

(Südhoff, 2007).

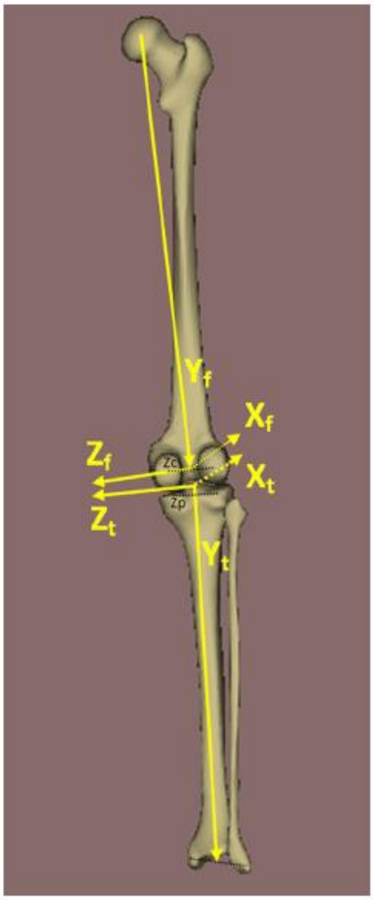

Figure 9: Body-coordinate system used to estimate the pseudo-kinematics.

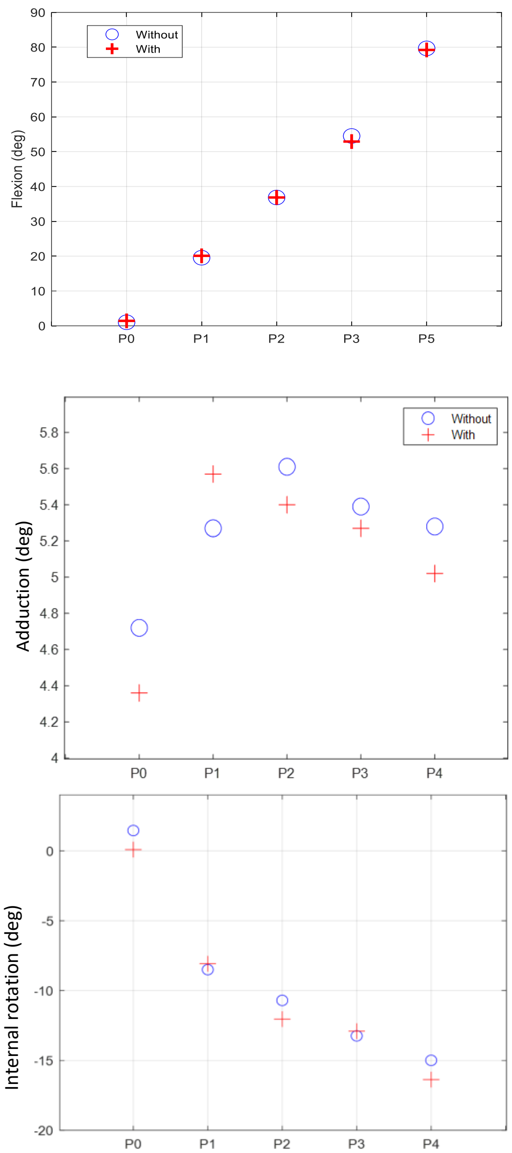

Figure 10: Results of the pseudo-kinematics for 15 subjects in five postures. Flexion-extension (top); adduction (middle); internal rotation (deg).

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Figure 10 exhibits the pseudo-kinematics of 15 subjects using the Evoke orthosis. In general, the kinematic found in this study is similar to the corresponding one found in Zeighami et al. (2017). In fact, the adduction angle presented in this study is in a midrange (4.4 – 5.6 degrees) between the normal population (around 2 degrees) and the severe OA population (10 degrees). There is slight reduction (less than one degree) in average of the adduction angle when wearing the Evoke orthosis. The Evoke alters by 2 degrees in the direction of internal rotation of the knee at P0 and P4 only. The knee flexion-extension angle was not altered or limited by using the Evoke orthosis.

3.4 Ground reaction forces under the instrumented foot.

In this study, we have instrumented the EOS cabinet by an AMTI force platform in order to measure the ground reaction force under the leg wearing the Evoke orthosis. Due the fact that we control the trunk and the ipsilateral and the contra-lateral position in space during the collect of data. We also control the fact that in the extreme squat position P4, the subject could use his hand to stabilize the body; however, this situation was also controlled. With the following conditions controlled, we can consider that any alteration in the vertical component of the ground reaction forces will be mainly due to the knee orthosis. Figure 11 shows the variation of the ground reaction forces under the instrumented foot in a normalized body-weight.

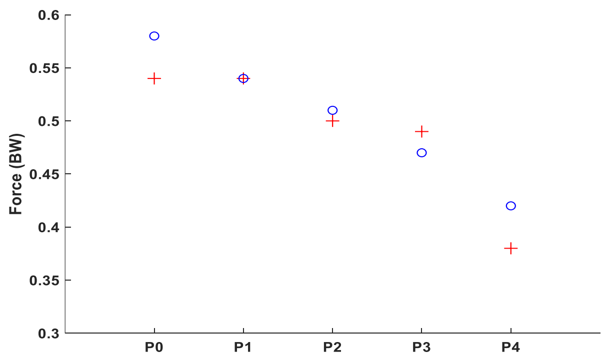

Figure 11. Average (N=15) vertical ground reaction forces in Body-weight.

The vertical ground reaction forces shows a slight reduction of the ground reaction forces in P0 and P4 by less than 0.1 BW. The knee orthosis did not alter the ground reaction forces under the instrumented foot.

Finding

This project was dedicated to a proof of concept for the use of 3D/2D registration techniques to investigate the effect of Evoke knee orthosis on the knee kinematics and contact point locations. One important issue in this study is that the postures adopted by each subjects, were accurately controlled in order to replicate the two conditions of wearing and not wearing the Evoke orthosis.

- The most important finding of this study is the Evoke orthosis induces an unloading at both the lateral and the medial compartment in mainly the standing posture P0 and the extreme posture P4. In fact, in average the unloading in the medial compartment varies from 7% to 18%; Whereas it varies from 2% to 45% in the lateral compartment. In general the unloading process is present for all of the posture, but vary between individuals. With respect to the literature found, the Evoke orthosis performed the best in this case.
- The contact point do not exhibit a single pattern, and is definitively a subject-dependant pattern. The major results from the contact parameters is that the effect of the knee orthosis is more pronounced for the standing posture and the extreme squatting posture P4. In between and due to the variability of the specific pattern it was difficult to find difference in P1 to P3 posture. However, in recent study with gait analysis we have used the contact parameters to estimate the contact forces between femur and tibia by a musculoskeletal modeling approach. The results demonstrate that contact point parameters can explain 32% of the variance of the contact force during treadmill walking for OA subjects (Zeighami et al., 2021). When we compare the actual data of our 15 subjects to our database of healthy and OA which undergoes similar squat movement, We find out that the Evoke can shift the point contact of the subject towards the healthy pattern.
- The kinematics pattern were not altered in sagittal plane for almost all subjects when wearing the knee orthosis. The frontal plane was slightly altered by reducing the adduction angle in average of the subject in the posture P0 and P4. We think that the mechanism induced by the helical axis of the Evoke help to maintain the kinematics of the knee in 3D during squat.

- 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 during gait anlaysis. Data on ground reaction forces slightly reduce in terms of loading when wearing the intrumented knee. We can conclude that the data provided here concur to the beneficial use of the knee orthosis.

Further investigations

- We are actually, developing and adapting a musculoskeletal with a personalization approach to estimate the contact forces acting at the level of medial and lateral compartment during the squat postures. This project can demonstrate that if bone-to-bone distance increases this means a decrease in the force acting at the tibio-femoral interface. Up to now, no data exist to corroborate this hypothesis. We have demonstrate in recent study that the application of personalized contact parameters help to identify pattern of forces contact during gait in healthy and severe OA subject. To be able to estimate the contact forces when wearing the Evoke orthosis, we are developing a new concept of stiffness in which we can estimate the resultant force and moment induced by the knee orthosis itself. We can then estimate more accurately the force acting at the tibial plateau. This can have tremendous effect in analyzing the progression of pathologies such as osteoarthritis of ligament injuries.
- In the actual study, all participant get the same type of correction i.e. the adduction angle induced during the design of the orthosis. The project continue to investigate the sensitivity of two specific design parameters, the lateral displacement of the knee hinge in the frontal plane as well as the angular correction of the knee orthosis. This investigation are on ongoing process.

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