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Evaluation of Joint Contact Forces in Subjects with Knee Osteoarthritis

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SUMMARY

Background. Abnormal joint loading is a contributor factor to develop and progress of osteoarthritic knee joint degeneration. Various approaches have been used to measure joint contact forces in the patients with knee osteoarthritis (OA). Evaluation of knee adduction moment based on inverse dynamic (ID) approach is a surrogate marker for medical compartment loading in people with knee OA. It is controversial whether joint loading increases in this group of subjects or not. Therefore, the aim of this study was to evaluate knee joint contact force in the subjects with OA based on OpenSIM modelling approach.

Methods. 10 knee osteoarthritic patients and 10 normal subjects with comparable age, height an weight were recruited in this study. A motion analysis system with 7 high-speed camera and a Kistler force plate was used to record the motions of the subjects while walking and the force applied on the legs, respectively. OpenSim software was used to evaluate joint contact forces.

Results. Although the mean value of the second peak of GRF in OA group decreased significantly compared to normal subjects (P-value = 0.0005), the mean value of the force applied on the leg in midstance phase increased significantly compared to normal subjects (P-value = 0.0005). The range of motion of ankle, hip and knee joints decreased in OA group compared to normal subjects (P-value < 0.05). The peaks of knee joint contact forces decreased significantly in OA subject (P-value > 0.001). Moreover, the peak of joint contact force of ankle in OA group was less than that of normal subjects.

Conclusions. The results of this study showed that the loads on knee joint (both based on moments and knee joints contact force omponents) of the subjects participated in this study was significantly less than that of normal subjects. This may be due to use of compensatory mechanisms selected by the subjects. It is highly recommended to repeat the research on more number of the subjects with various severities of knee joint OA.

KEY WORDS

Knee osteoartrities; load; joint contact force; moment; diet; joint loading; knee joint.

INTRODUCTION

Knee osteoarthritis (OA) influences the abilities of the subjects during daily activities and finally influences their quality of life (1, 2). Most of the subjects with knee OA have pain while walking, decrease in the knee range of motion (ROM) and instability of knee joint (which influence their stability in standing and walking). They have to use some mechanism to reduce their pain while walking (2, 3).

It seems that abnormal loading condition is a contributor factor to develop and progress of joint degeneration (4, 5).

Unfortunately, it is not too practical to measure directly the loads applied on knee while walking. Assessment of muscles forces and joint contact forces are essential to understand how knee OA develops and progresses. Various approaches have been used to measure joint contact forces in this group of subjects (5, 6). The most accurate approach is to use direct measurement technique in this regard. However, there are very few studies which directly measured the loads of knee joint while walking.
Evaluation of knee adduction moment based on inverse dynamic (ID) approach is a surrogate marker for medical compartment loading in people with knee OA (5). However, it is controversy wheather adduction moment of knee joint is a validated predictor parameter for knee joint loading (although there is a moderate correlation between the peak of the adduction moment and knee joint OA severity) (7). Moreover, it does not take into account muscles co-contraction (in subjects with knee OA, there is a co-contraction of hamstring and quadriceps muscles to stabilize knee joint) (5). Based on the results of the recent studies, decreased knee adduction does not guarantee decreased medial contact forces measured based on knee prosthesis sensor while walking (6, 8). Based on the results of the study done by Meireles *et al.*, mechanical loading of knee joint was not significantly higher in early OA subjects (based on knee adduction moment and knee contact force) (8). However, mechanical loading was higher significantly in well stablished OA compared to early OA subjects. Another way to evaluate the loads applied on knee joint is based on modelling approach (5). Currently knee joint contact force can be evaluated by use of some software such as OpenSim and Anybody. This may be done based on EMG-driven-musculoskeletal modelling (9). There were a few studies based on this approach in literature. The results of these studies showed that subjects with knee OA showed higher medial joint loading in early stance phase (9). In other study, it was showed that the peak of knee joint contact force decreased with OA severity which may be due to compensatory mechanism used by this group of subjects (4). Moreover, it was shown that the loads applied on knee joint depends on duration of walking in OA subjects (the first peak of knee joint contact force increased significantly during weight acceptance phase after 30 to 40 minutes of walking) (10).
Based on the above-mentioned studies, adduction moment of knee joint is not a symbol for knee joint loading (however it was measured in most of available studies on knee joint loading). Moreover, it is controversial whether joint loading increases in this group of subjects or not. Therefore, the aim of this study was to evaluate the knee joint loading in the subjects with OA. The main hypothesis associated with this study was that the knee joint contact force was higher in the subjects with knee OA compared to normal subjects.

METHODS

10 subjects with knee osteoarthritis were recruited in this study. Moreover, there was a control group matching with the first group based on age and height. The first group was selected from those referred to Rehabilitation Faculty of Isfahan University of Medical Sciences physical therapy Clinic or for bracing between 2017 and 2018. The main inclusion criteria to select the subjects were age between 40 and 60 with knee severity OA grade 2 or more based on KL grade with abilities to stand and walk independently (without use of crutch or any other assistive devices) and without any other musculoskeletal disorders which influence the abilities of the subjects in standing and walking.
Ethical approval was obtained from Isfahan University of Medical Sciences, ethical committee. (Protocol Number IUM5698067. - date: 2018/05) Furthermore, we followed Helsinki Protocol. Moreover, a consent form was assigned by each participant before data collection.

Equipment

A motion analysis system with 7 high-speed camera (Qualisys motion analysis system, Switzerland) was used to record the motions of the subjects while walking. The force applied on the legs were recorded by a Kistler force plate. Range of ankle, knee, hip, pelvic and trunk motions, peaks of ground reaction force (GRF), peaks of the moments applied on ankle, knee and hip joints and peaks of joint contact force of ankle, knee and hip were the parameters selected in this study.

Procedure

The subjects were asked to walk with comfortable speed along a 10-meter walkway to collect 5 successful trials. The data of both force plate and camera were collected with the frequency of 120 Hz and were filtered with Butterworth low-pass filter with cut-off frequency of 10 Hz
Some reflective markers were attached on both right and left 1st and 5th metatarsal heads, heels, medial and lateral malleolus, medial nad lateral knee epicondyles, anterior and superior iliac spine and greater trochanter. The data were collected with QTM software and were saved as c3d file In MOKKA, an open-source software powered by open-source library Biomechanical Toolkit (BTK), the output file were prepared to be used in OpenSim software. OpenSim is open-source software for modelling and simulating musculoskeletal systems created and developed by Stanford University since 2010 (11). The Rajagopal model was used which consists of a model with 23 degrees of freedom and 95 actuators for muscles. The model was scaled by the use of static trial which was collected from each subject while standing in anatomical position. During scaling, the Root Mean Square value which is the difference between the same virtual and

real markers was less than 0.03 (m) for each subject. In the next step, inverse kinematics and inverse dynamics were run based on the scaled model and the center of mass was adjusted by the use of Residual Reduction Algorithm (RRA). All muscle excitation have been computed using Computer Mmuscle Control (CMC) tool. In the next step, joint contact force was analyzed based on the CMC outputs.

Data management

The peaks of ground reaction force (GRF), moments applied on the joints and joint contact forces were normalized to body weight (BW), body mass (Kg) and weight (N), respectively.

Data analysis

The normal distribution of the aforementioned parameters were evaluated by use of the Shapiro-Wilk test. Since the data had a normal distribution, two-sample test was used to determine the difference between the mean values of the aforementioned parameters (the significant point was set to 0.05). All statistical tests were done by use of SPSS software (version 21).

RESULTS

Table I shows the characteristics of the subjects participated in this study. As can be seen from this table, there was no significant difference between the mean values of age, weight and height of the participants.

Table II represents the mean values of spatiotemporal gait parameters of normal and those with knee OA. Those with knee OA walked with velocity of 0.655 m/s ± 0.224 compared to 1.27 ± 0.146 m/s of normal subjects (P-value of difference = 0.0005). There was a significant difference between the mean values of all spatiotemporal gait parameters in OA group compared to normal subjects (P-value < 0.05).

The mean values of ground reaction force component (GRF) of both group are also shown in **table II**. Although the mean value of the second peak of GRF in OA group decreased significantly compared to normal subjects (P-value = 0.0005), the mean value of the force applied on the leg in midstance phase increased significantly compared to normal subjects (P-value = 0.0005).

The pelvic range of flexion/extension motion did not differ significantly between normal and OA subjects (P-value = 0.18). However, the range of motion of pelvic in frontal and transverse planes decreased significantly in OA group. The ROM of ankle, hip and knee joints decreased in OA group compared to normal subjects (P-value < 0.05). The interesting point was that the ROM of trunk motion decreased in OA group, however, it was significant only for flexion extension and rotation (**table III**).

Although the mean values of the moments applied on lower limb joints decreased in OA significantly for most of the joints, the mean value of the second peak of adduction moment in OA group increased compared to normal subjects. **Table IV** summarizes the mean values of the peaks of the moments of leg joints in both groups of normal and OA subjects.

The mean values of joint contact force components (hip, knee, and ankle joints) are summarized in **table V**. As can be seen from this table, the peak of ground reaction force components of hip joints in vertical direction, anteroposterior and mediolateral directions decreased significantly in OA subjects compared to normal subjects. The interesting point was that the peaks of knee joint contact forces decreased significantly in OA subject (P-value < 0.05). The peak of joint contact force of ankle in OA group was less than that of normal subjects.

DISCUSSION

Those with knee osteoarthritis suffer from some problems such as pain while standing and walking, knee joint instability, and reduction in knee joint range of motion. They may use some compensatory mechanisms to reduce their pain while walking. There are some research which evaluated knee joint contact forces by use of adduction moment or by modeling to determine the joint contact force in those with knee osteoarthritis compared to normal subjects (1, 3, 4, 6, 7, 12, 13). Although based on adduction moment, which is indirect measure of knee joint loading, the loads applied on knee joint increased in those with OA, modeling or direct measure of knee joint modeling did not support it (8). Therefore, it is controversial whether knee joint loading increased in those with knee OA or not.

The results of this study confirmed that both knee joint contact force components and moments decreased significantly in OA subjects compared to normal subjects (**tables IV, V**). The interesting point was that the knee joint contact force in other joints of lower limb also decreased in OA group. The main question posted here is why joint contact forces decreased in the subjects with knee osteoarthritis?

The interesting point which should be considered here is that the severity of knee OA of the subjects participated in this study was more than 2 based on KL grade. Therefore, they have pain while walking and use a compensatory mechanism to reduce their pain in walking. The main compensatory mechanism selected by this group of the subjects is reducing walking speed. As can be seen from the results of the current study, the mean values of spatiotemporal gait parameters of the OA group decreased significantly compared to normal subjects (**table II**). The mean value of walking speed of OA group was 0.655 ± 0.224 m/s compared to 1.27 ± 0.146 for

Table I. The characteristics of the subjects participated in this study.

	Age	Weight	Height	OA severity
Normal	51.3 ± 2.1	72.1 ± 9.2	158.2 ± 4.8	------
OA	50 ± 3.22	73.33 ± 14.5	156.86 ± 5.4	KL grade > 2
P-value	0.12	0.1	0.14	---------

Table II. The mean values of spatiotemporal gait parameters and ground reaction forces of both OA and normal matched groups.

	Stride length	Speed	Cadence	Stance precentage	GRF Y1	GRF Y0	GRF Y2	GRF X1	GRF X2
Normal	1.38 ± 0.144	1.27 ± 0.146	109.95 ± 8.56	58 ± 2	10.7 ± 0.74	7.47 ± 0.725	11.34 ± 0.61	1.33 ± 0.67	2.1 ± 0.37
OA	0.896 ± 0.251	0.655 ± 0.224	85.86 ± 12.59	66.75 ± 3.25	10 ± 0.31	9.14 ± 0.33	10.35 ± 0.366	0.93 ± 0.4	1.22 ± 0.477
P-value	0.0005	0.0005	0.0005	0.0005	0.01	0.0005	0.0005	0.055	0.005

Table III. The range of motions of different joints of normal and those with OA.

Parameters	Pelvic Flex/Ext	Pelvic Abd/Add	Pelvic Rotation	Hip Flex/Ext	Hip Abd/Add	hip Rotation	Knee Flex/Ext	Ankle Planta/ Dorsiflexion	Lumbar Flex/Ext	Lumbar Abd/Add	Lumbar Rotation
Normal	5.53 ± 4.7	10.25 ± 3.27	15.47 ± 6.68	46.65 ± 7.36	14.94 ± 3.46	19.23 ± 6.36	63.87 ± 6.6	31.8 ± 4.18	9.8 ± 6.1	13 ± 4.2	37.55 ± 13.37
OA	4.04 ± 1.35	8.35 ± 3.42	9.17 ± 2.67	35.3 ± 8.016	17.3 ± 2.62	11.8 ± 2.5	52.79 ± 11.8	27.32 ± 8.8	4.37 ± 1.49	11 ± 4.15	96.2 ± 5.22
P-value	0.18	0.08	0.006	0.0005	0.042	0.0015	0.002	0.0029	0.015	0.12	0.0005

Table IV. The moments of different joints of normal and those with OA (Nm/BM).

	Hip Extension	Hip Flexion	Hip Abduction First peak	Hip Abduction second peak	Knee Flexion	Knee Extension	Ankle Dorsi-flex	Ankle Plantar-flex
Normal	0.536 ± 0.186	1.044 ± 0.31	0.51 ± 0.151	0.81 ± 0.035	0.175 ± 0.086	0.71 ± 0.3	0.311 ± 0.088	1.47 ± 0.2
OA	0.194 ± 0.108	0.406 ± 0.198	0.435 ± 0.135	0.57 ± 0.043*	0.081 ± 0.056	0.164 ± 0.161	0.056 ± 0.036	1.33 ± 0.25
P-value	0.0005	0.0005	0.113	0.0005	0.035	0.0005	0.0005	0.16

Table V. The mean values of lower limb joint contact force of normal and those with OA (N/BW).

	Hip F × 1	Hip F × 2	Hip FY1	Hip FY2	Hip FZ	Knee FX1	Knee FX2	Knee FY1	Knee FY2	Knee FZ	Ankle FX1	Ankle FX2	Ankle FY1	Ankle FY2	Ankle FZ
Normal	0.892 ± 0.42	3.18 ± 0.91	3.68 ± 1.09	5.37 ± 1.23	1.04 ± 0.45	0.43 ± 0.33	9.6 ± 0.37	4.04 ± 1.08	3.54 ± 0.45	0.365 ± 0.13	0.875 ± 0.216	2.59 ± 0.76	2.96 ± 0.69	4.9 ± 0.6	0.38 ± 0.07
OA	0.26 ± 0.17	1.4 ± 0.48	1.97 ± 0.51	3.14 ± 0.41	0.72 ± 0.14	0.146 ± 0.076	1.56 ± 0.36	2. ± 0.27	2.71 ± 0.24	0.207 ± 0.043	0.505 ± 0.08	1.67 ± 0.6	2.64 ± 0.366	4.2 ± 0.05	0.226 ± 0.076
P-value	0.0005	0.0005	0.028	0.0005	0.026	0.08	0.0005	0.0005	0.0005	0.001	0.0005	0.002	0.118	0.005	0.0005

normal subjects. Therefore, it is cleared that this compensatory mechanism was successful in this group of subjects, as it decreases the range of motion of the joints (**table III**), reduce joint moments (**table IV**), and finally joint contact forces (**table V**). Although use of this compensatory mechanism was successful to reduce joint loading, especially in knee joint during push off and heel contact (loading response), it increases the peak of ground reaction forces in midstance. The reason is due to decrease in knee flexion angle. Therefore, it can be concluded that joint contact forces decrease significantly in OA subjects, but this is mostly due to pain and use of compensatory mechanisms. It may be concluded that an increase in severity of this disease in those who had grade 2 may not be due to an increase in knee joint contact force and other parameters such as knee alignment may be more important (14). These subjects use a compensatory mechanism which is successful in this regard.

As it was mentioned clearly in introduction, it is not too practical to evaluate knee joint loading only based on knee adduction moment. Knee abduction moment value is related mostly to laxity of knee joint in frontal plane and alignment of knee joint. However, both muscles and knee alignment are two important parameters which influence knee joint contact forces (14, 15)

It has been mentioned by Marouane and Shirazi, that knee adduction moment has limitation in its ability to provide information about loading of the knee joint, as it is based on inverse dynamic approach and does not include the muscle co-contraction at knee, therefore underestimate the loads across the knee joint. It was concluded that the efficacy of EMG-driven musculoskeletal modeling is high to predict the different loading pattern for person with medial knee osteoarthritis and healthy control (16).

There was another study in literature which did not support the theory of an inversion in knee joint contact force in those with knee OA (8). It was confirmed that mechanical loading was not significantly higher in early OA subjects compared to controls (based on both adduction moment and joint contact force component). This was also supported by the research done by Baret *et al.* and Duffell *et al.* (no difference between KAM in those in early stage of OA and healthy subjects) (17, 18). The results of the current study did not support this assumption that mechanical loading was higher in established OA compared to early OA subjects. It should be noted that both group of healthy and OA subjects walked with comfortable speed in this study. The duration of walking in OA group also influence the joint contact force. Long duration walking in the patients with knee OA leads to fatique of knee extensors, loss of effective shock absorbation, and increase the rate of joint loading. However, short duration walking was evaluated in this study (10).

The results of the current study confirmed that, based on modeling approach done by Open-SIM, the load applied on knee joints (both based on moments and joint contact force components) decreased significantly which is due to use of compensatory mechanism used by OA subjects, and reduced walking speed. The results of this study could not establish whether increase in knee joint contact force is responsible for knee joint symptom of OA or not. Therefore, it can be concluded that decrease in walking speed, as a results of knee OA or due to compensatory mechanism is a successful strategy to reduce knee joint loading.

The main limitation associated with this study was that only OA subjects with severity more than 2 participated in this study. It is highly recommended that the subjects with various knee OA were recruited in the future studies.

CONCLUSIONS

The results of this study showed that the loads applied on knee joint (both based on moments and knee joints contact force omponents) of the subjects participated in this study was significantly less than that of normal subjects. This may be due to use of compensatory mechanisms selected by the subjects. It is highly recommended to repeat this research on more number of the subjects with various severity of knee joint OA.

FUNDINGS

None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

MK: data collection. HAA: patients evaluation. MRR: data analysis. MTK: supervision of the project and writing the paper.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

REFERENCES

1. Al-Zahrani KS, Bakheit AMO. A study of the gait characteristics of patients with chronic osteoarthritis of the knee. Disability and Rehabilitation 2002;24(5):275-80.
2. Farr Ii J, Miller LE, Block JE. Quality of life in patients with knee osteoarthritis: a commentary on nonsurgical and surgical treatments. Open Orthop J 2013;7:619-23.
3. Favre J, Jolles BM. Gait analysis of patients with knee osteoarthritis highlights a pathological mechanical pathway and provides a basis for therapeutic interventions. EFORT Open Rev 2017;1(10):368-74.
4. Adouni M, Shirazi-Adl A. Evaluation of knee joint muscle forces and tissue stresses-strains during gait in severe OA versus normal subjects. J Orthop Res 2014;32(1):69-78.
5. Kumar D, Manal KT, Rudolph KS. Knee joint loading during gait in healthy controls and individuals with knee osteoarthritis. Osteoarthritis Cartilage 2013;21(2):298-305.
6. D'Lima DD, Fregly BJ, Patil S, Steklov N, Colwell CW, Jr. Knee joint forces: prediction, measurement, and significance Proceedings of the Institution of Mechanical Engineers Part H. J Eng Med 2012;226(2):95-102.
7. Konrath JM, Karatsidis A, Schepers HM, Bellusci G, de Zee M, Andersen MS. Estimation of the Knee Adduction Moment and Joint Contact Force during Daily Living Activities Using Inertial Motion Capture. Sensors (Basel) 2019;19(7):1681.
8. Meireles S, De Groote F, Reeves ND, Verschueren S, Maganaris C, Luyten F, Jonkers I. Knee contact forces are not altered in early knee osteoarthritis. Gait Posture 2016;45:115-20.
9. Winby CR, Gerus P, Kirk TB, Lloyd DG. Correlation between EMG-based co-activation measures and medial and lateral compartment loads of the knee during gait. Clin Biomech (Bristol, Avon) 2013;28(9-10):1014-9.
10. Farrokhi S, Jayabalan P, Gustafson JA, Klatt BA, Sowa GA, Piva SR. The influence of continuous versus interval walking exercise on knee joint loading and pain in patients with knee osteoarthritis. Gait Posture 2017;56:129-33.
11. Delp SL, Anderson FC, Arnold AS, Loan P, Habib A, John CT, Guendelman E, Thelen DG. OpenSim: open-source software to create and analyze dynamic simulations of movement. IEEE Trans Biomed Eng 2007;54(11):1940-50.
12. Amin S, Luepongsak N, McGibbon CA, LaValley MP, Krebs DE, Felson DT. Knee adduction moment and development of chronic knee pain in elders. Arthritis Rheum 2004;51(3):371-6.
13. Baert IAC, Jonkers I, Staes F, Luyten FP, Truijen S, Verschueren SMP. Gait characteristics and lower limb muscle strength in women with early and established knee osteoarthritis. Clin Biomech (Bristol, Avon) 2013;28(1):40-7.
14. Adouni M, Shirazi-Adl A. Partitioning of knee joint internal forces in gait is dictated by the knee adduction angle and not by the knee adduction moment. J Biomech 2014;47(7):1696-703.
15. Marouane H, Shirazi-Adl A. Sensitivity of medial-lateral load sharing to changes in adduction moments or angles in an asymptomatic knee joint model during gait. Gait Posture 2019;70:39-47.
16. Winby CR, Gerus P, Kirk TB, Lloyd DG. Correlation between EMG-based co-activation measures and medial and lateral compartment loads of the knee during gait. Clin Biomech (Bristol, Avon) 2013;28(9-10):1014-9.
17. Baert I, Jonkers I, Staes F, Luyten F, Truijen S, Verschueren S. Gait characteristics and lower limb muscle strength in women with early and established knee osteoarthritis. Clin Biomech (Bristol, Avon) 2013;28(1):40-7.
18. Duffell LD, Southgate DFL, Gulati V, McGregor AH. Balance and gait adaptations in patients with early knee osteoarthritis. Gait Posture 2014;39(4):1057-61.