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The Effectiveness of a Newly Designed Orthosis on Knee Contact Forces in Subjects with Knee Osteoarthritis

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SUMMARY

Background. This study was aimed to assess the effectiveness of a newly designed orthosis on knee contact forces in subjects with knee osteoarthritis (OA).

Material and methods. Five patients with OA participated in the study. All had knee OA on the medial side according to the American College of Rheumatology criteria, medial knee pain and radiographic osteophyte on the medial side of knee joint. The knee joint contact forces were determined by the use of Open Simm software under two conditions, namely, walking with and without the orthosis.

Results. There was no significant difference between the mean values of walking speed, stride length and cadence during walking with and without the orthosis. The mean and standard deviation (SD) values of the first and second peaks of the knee joint contact force in a vertical direction were 2.83±0.26 and 3.17±1.16 N/BW, respectively, compared to 2.54±0.22 and 2.54±0.958 N/BW in walking with and without the orthosis ($p < 0.05$).

Conclusion. The results of this study confirmed that the new design of orthosis decreases the joint contact forces, due to reduction in muscle performance needed to stabilize the knee joint.

Key words: knee, osteoarthritis, orthosis, joint contact force, open Simm

BACKGROUND

Knee osteoarthritis (OA) is a common musculoskeletal disorder in the elderly and a major cause of disability [1]. It is estimated that 85% of all people over age 60 have some degree of OA [2]. In 1995, about 20 million people (15% of the population) in the United States of America (USA) were reported to have arthritis, and this figure is predicted to increase to 59 million by 2020. OA may result from obesity, kneeling and squatting, joint trauma, immobilization and joint hypermobility. There is strong evidence that the load applied to the knee joint plays a significant role in increasing the incidence of knee OA (the pattern of load distribution in the knee joints in subjects with knee OA differs from that seen in normal subjects) [3,4].

Individuals with knee OA may complain of pain, limitation in the knee joint range of motion, instability during walking and fear of falling [4]. Treatment modalities such as conservative and surgical approaches have been used for managing patients with knee OA. Conservative treatment includes rest, joint immobilization, weight management to reduce BMI, use of foot orthosis and offloading knee orthoses [5]. It is believed that an offloading orthosis reduces adduction moments applied to the knee joint [6,7].

Various kinds of knee braces, such as the Generation II brace, the medial unloading Monarch brace, and the Vista CA brace have been used for the management of the patients with knee OA [5,7-9]. However, patients experience some problems using knee orthoses such as a tendency of the brace to migrate distally as a result of muscle contraction. Moreover, it is not possible to change the alignment of these braces during the follow-up period [7,10].

A new type of knee orthosis has been designed to address some of these problems. The new solutions include introducing a modular structure to change the alignment of the components with respect to each other based on patients' needs. The distal migration of this orthosis is not significant enough to influence the function of the orthosis. The components of this orthosis have been designed so that the magnitude of the corrective force can be changed according to the patient's need [7]. The newly designed orthosis was tested on two patients to determine its effect on knee joint kinematics and adduction moment. Previous studies have shown that the efficiency of an orthosis can be determined based on the adduction moment and kinematics of the knee joint during walking. The main differences between the new-design knee orthosis and other available orthoses include: design of the orthosis, which consists of two main inside and outside shells, adjustability of the orthosis in both the sagittal and coronal planes, adjustability of the orthosis regarding the corrective force and ability of the orthosis to remain stationary while walking [7]. Figure 1 shows the new design of the orthosis evaluated in this study.

Fantini et al. showed that the use of knee orthoses with 8 and 9 degree valgus angulation decreased the knee adduction angular impulse by between 25% and 36% [6]. Gaasbeek et al. also showed that using an offloading orthosis reduced knee adduction [8]. As was mentioned, the efficiency of various orthoses used by OA subjects was determined based on their effects on the adduction moment [5-8]. However, the effect of orthosis on the reduction of joint contact forces has not been evaluated. Therefore, the aim of this study was to determine knee joint contact forces

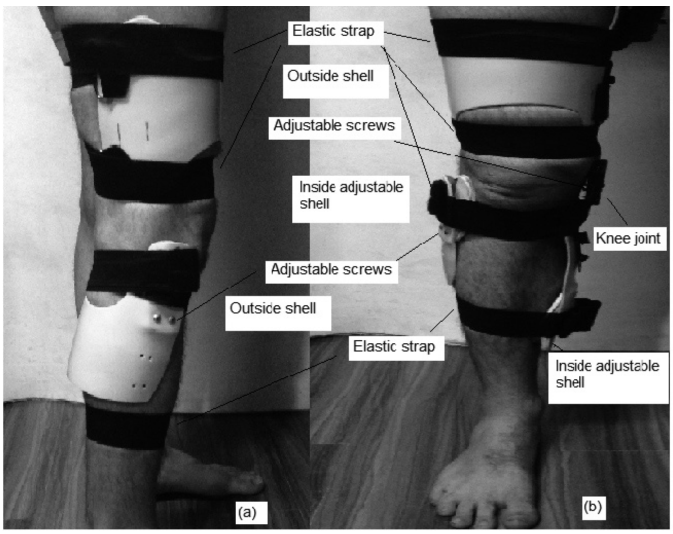

Fig. 1. The new design of orthosis evaluated in this study, lateral view (a), anterior view (b)

Tab. 1. The characteristics of the subjects participating in the study

	Weight (N)	Height (m)	Age (year)
Mean±SD	722±27.85	1.568±0.065	53.2±2.48

in patients with knee OA with and without orthosis. The study also investigated the efficiency of the newly designed orthosis. The main hypothesis of this study was that the newly designed knee orthosis would significantly reduce knee joint contact forces.

MATERIAL AND METHOD

A group of subjects with knee OA were recruited in this study. Table 1 shows the characteristics of the participants. Subjects were diagnosed with knee OA according to the American College of Rheumatology criteria: medial knee pain and radiographic osteophytes on the medial side of the knee joint [11,12]. The severity of knee OA of the subjects was 3, defined by the Kellgren and Lawrence grade (K-L grade) based on X-ray as described in the Atlas of Standard Radiography [11]. Subjects were excluded from the study if they had other musculoskeletal disorders that could influence their ability to stand and walk. Ethical approval was obtained from the Isfahan University of Medical Science Ethics Committee. Informed consent was obtained from each participant before data collection.

Equipment*:* A 3-D motion analysis system, with 7 high speed cameras (Qualysis Motion analysis system) and a Kistler force plate were used to record body movements during walking and the forces applied to the lower limb, respectively.

Parameters*:* The following parameters were recorded: spatiotemporal gait parameters (stride length, cadence and walking speed), force applied to the lower limb (mediolateral, anteroposterior and vertical), knee joint contact forces and range of motion.

Procedure*:* 22 markers were attached on the medial and lateral sides of the right and left knee and ankle joints, first and fifth metatarsal head, right and left heel, sacrum, right and left anterior superior iliac spine, right and left acromioclavicular joints, sternum, C7 and head. Moreover, 4 marker clusters, consisting of 4 markers, were attached to the anterolateral surface of thigh and shank (right and left), respectively. Subjects were asked to walk along a level surface with and without the orthosis. Ten successful trials (5 trials for each condition) were collected. The data were collected with a sampling frequency of 100 Hz. The collected data were filtered (Butterworth low pass filter) at the frequency of 10 Hz and split to the gait cycle interval using heel strike data.

The trajectory of markers and the force applied to the limb during walking were collected by Qualysis Track Manager (QTM) software. The markers were labeled and exported as 3D. The 3D files were opened in Mokka software. Mokka software was used to produce files in Trc format. The Open Simm software was used to evaluate the kinematics and moments of knee joint, and the force applied to the knee joint. Figure 2 shows the procedure used in this study to calculate the joint contact forces by Open Simm software. The normal distribution of the parameters was evaluated using the Shapiro-Wilk test. Since the

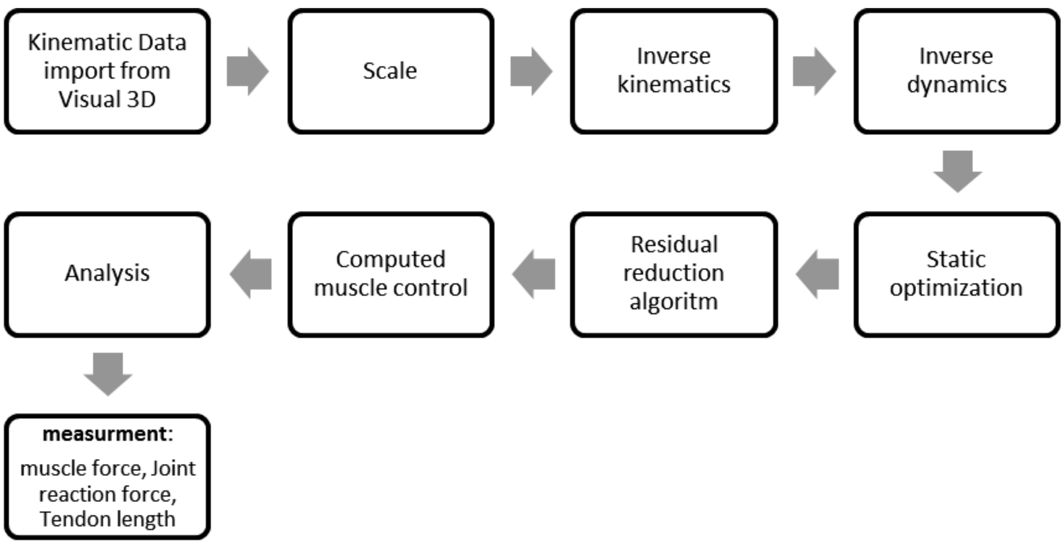

Fig. 2. The procedures used to determine joint contact force in walking with and without the knee orthosis

parameters had a normal distribution, the paired T test was used for final analysis (α was set at 0.05).

RESULTS

The spatiotemporal gait parameters of OA subjects while walking with and without the knee orthosis are shown in Table 2. The mean and SD values of walking speed were 49.97±7.22 and 45.79±0.65 m/min without and with orthosis, respectively. There was no significant difference (p-value>0.05) between the mean values of walking speed, stride length and cadence during walking with and without the orthosis. The first and second peaks of the ground reaction force in the vertical direction during walking without the orthosis were 0.969±0.107 and 1.04±0.03 N/BW, respectively. In addition, the mean and SD values of the first and second peaks of the ground reaction force during walking with the orthosis were 1.01±0.041 and 0.99±0.041 N/BW, respectively. These values were not significantly different (p-value>0.05).

The mean values of the anteroposterior ground reaction force during walking with (0.126±0.019 N/BW) and without (0.122±0.02 N/BW) the orthosis were similar (p value = 0.18). The mean values of the knee joint range of motion during walking with and without the offloading knee orthosis were 54.28±8.19 and 54.12±10.86 degrees, respectively (p-value = 0.477).

The knee joint contact forces in three dimensions were the other parameters that were selected in this study. The mean values of the first and second peaks of the knee joint contact force in the vertical direction were 2.83±0.26 and 3.17±1.16 N/BW, respectively, compared to 2.54±0.22 and 2.54±0.958 during walking without and with the orthosis. These values were not statistically different (p value > 0.05).

The peak of the joint contact force in the mediolateral direction was 0.248±0.082 during walking without the orthosis compared to 0.222±0.04 N/BW during walking with the orthosis (p-value = 0.29).

DISCUSSION

Patients with knee osteoarthritis suffer from pain and limitation of knee joint function during walking [4,13]. Various treatment approaches have been used to improve the walking pattern and functional ability of subjects with knee OA during walking. A new type of knee orthosis has been designed to improve knee joint alignment and decrease the loads applied to the knee joint during walking [7]. Therefore, the aim of this study was to evaluate the knee joint contact force in subjects with knee OA while walking with this orthosis.

The results of this study showed that although there was no significant difference between the peaks of vertical force applied to the lower limb during walking with and without knee orthosis. Moreover, the walking speed, stride length and cadence did not differ significantly between the two test conditions, Table 2. However, the knee joint contact forces decreased significantly (especially vertical forces) while subjects walked with the knee orthosis. The reason for this finding is not apparent; however, it may be due to improved alignment of the knee joint with the use of the new knee orthosis [7].

The knee joint range of motion did not differ significantly while walking with orthosis, Table 2. This may suggest that the orthosis did not restrict the motion of knee joint. In other words, patients have enough comfort ability to walk with the newly designed knee orthosis. The main problem of the previous orthoses was their distal migration [7]. The previous orthoses move distally during walking and restrict the motion of the knee joint while walking. However, the distal migration of the orthosis in the new design is restricted due to its specific design [7]. It has two inner flexible and outer rigid structures, which improves orthosis fitting and decreases its distal migration. Therefore, it can be concluded that the newly designed orthosis did not decrease the knee joint range of motion due to reducing the distal migration of the orthosis.

Tab. 2. The mean values of the gait parameters during walking with and without the knee orthosis

Subjects	GRF-Fy1 (N/BW)	GRF-Fy2 (N/BW)	GRF-Fx1 (N/BW)	GRF-Fx2 (N/BW)	GRF-Fz (N/BW)	Knee range of motion	JRF-Fx (N/BW)	JRF-Fy1 (N/BW)	JRF-Fy2 (N/BW)	JRF-Fz (N/BW)	Stride length (m)	Speed (m/min)	Cadence (steps/min)
Without orthosis	0.969± 0.107	1.04± 0.03	0.122± 0.02	0.142± 0.027	0.028± 0.009	54.12± 10.86	1.25± 0.36	2.83± 0.26	3.17± 1.160	0.248± 0.082	0.986± 0.128	49.97± 7.32	86.83± 10.59
With orthosis	1.01± 0.041	0.99± 0.114	0.126± 0.019	0.136± 0.02	0.025± 0.012	54.28± 8.19	1.27± 0.45	2.54± 0.227	2.54± 0.958	0.222± 0.04	1.04± 0.085	45.79± 0.65	88.2± 7.05
p-value	0.2	0.19	0.18	0.31	0.217	0.477	0.428	0.025	0.05	0.29	0.21	0.14	0.37

GRF: Ground Reaction Force, N: Newton, BW: Body Weight, Fy: Vertical Force, Fx: Anteroposterior Force, Fz: Mediolateral Force, JRF: Joint Contact Force, m: meter

The most important advantage of the new knee orthosis is its effect on knee contact forces during walking. This is the first study to evaluate the knee joint contact force using Open Simm software, which is newly developed software in neuromuscular modeling. The joint contact forces consist of external forces (ground reaction force and body weight) and internal forces (muscle, ligament and joint capsule tensions) [14]. As can be seen in Table 2, the mean values of the peaks of the ground reaction forces did not decrease significantly. Therefore, the decrease in the joint contact force may be related to a decrease in the activity of the muscles surrounding the knee joint.

The newly designed orthosis decreased the joint contact force due to the role of orthosis in improving the alignment and stability of the knee joint. The reduction in knee joint stability was compensated for by orthosis stiffness and alignment in the mediolateral direction [7]. It should be emphasized that the ground reaction force did not differ significantly while walking with the orthosis as the orthosis did not influence the abilities of the subjects during walking (there was no difference between the speed of the subjects while walking with and without the orthosis). However, the knee joint contact force decreased significantly due to reduced demand for muscle contraction to stabilize the knee joint.

There are limitations to the current study. The sample size was small, limiting the generalizability of the findings. Only the knee contact force was analyzed; hence, it is difficult to determine the effects of the newly designed orthosis on other forces acting on the knee joint. No data was collected on other health outcomes such as muscle activity around the knee joint using EMG, and quality of life of patients using this orthosis. In addition, the cost-effectiveness of the orthosis was not examined in the present study. It is hoped that these limitations can be addressed in future studies. This is the first study that uses Open Simm stimulation to determine the knee joint contact force while walking with the new orthosis.

CONCLUSION

The results of this study confirmed that the new design of orthosis decreases the joint contact forces, due to reduction in muscle performance needed to stabilize the knee joint.

REFERENCES

1. Zhang Y, Jordan JM. Epidemiology of osteoarthritis. Clin Geriatr Med 2010;26:355-69.
2. Felson DT, Nevitt MC. Epidemiologic studies for osteoarthritis: new versus conventional study design approaches. Rheum Dis Clin North Am 2004; 30: 783-97.
3. Baliunas AJ, Hurwitz DE, Ryals AB, et al. Increased knee joint loads during walking are present in subjects with knee osteoarthritis. Osteoarthritis Cartilage 2002; 10: 573-9.
4. Esrafilian A, Karimi MT, Amiri P, Fatoye F. Performance of subjects with knee osteoarthritis during walking: differential parameters. Rheumatol Int 2013.
5. Foroughi N, Smith R, Vanwanseele B. The association of external knee adduction moment with biomechanical variables in osteoarthritis: a systematic review. Knee 2009; 16: 303-9.
6. Fantini Pagani CH, Potthast W, Bruggemann GP. The effect of valgus bracing on the knee adduction moment during gait and running in male subjects with varus alignment. Clin Biomech (Bristol, Avon) 2010; 25: 70-6.
7. Esrafilian A, Karimi MT, Eshraghi A. Design and evaluation of a new type of knee orthosis to align the mediolateral angle of the knee joint with osteoarthritis. Adv Orthop 2012: 104927.
8. Gaasbeek RD, Groen BE, Hampsink B, van Heerwaarden RJ, Duysens J. Valgus bracing in patients with medial compartment osteoarthritis of the knee. A gait analysis study of a new brace. Gait Posture 2007; 26: 3-10.
9. Gabriel SM, Clifford AG, Maloney WJ, O'Connell MK, Tornetta Iii P. Unloading the OA Knee with a Novel Implant System. J Appl Biomech 2012.
10. Pollo FE. Bracing and heel wedging for unicompartmental osteoarthritis of the knee. American journal of knee surgery 1998; 11: 47-50.
11. Kellgren JH, Lawrence JS. Radiological assessment of osteoarthrosis. Ann Rheum Dis 1957; 16: 494-502.
12. Hochberg MC, Altman RD, Brandt KD, Clark BM, Dieppe PA, Griffin MR. Guidelines for the medical management of osteoarthritis. Part2.Osteoarthritis of the knee. ARTHRITIS & RHEUMATISM 1995; 38: 1541-6.
13. Childs JD, Sparto PJ, Fitzgerald GK, Bizzini M, Irrgang JJ. Alterations in lower extremity movement and muscle activation patterns in individuals with knee osteoarthritis. Clinical Biomechanics 2004; 19: 44-9.
14. Shelburne KB, Torry MR, Steadman JR, Pandy MG. Effects of foot orthoses and valgus bracing on the knee adduction moment and medial joint load during gait. Clin Biomech (Bristol, Avon) 2008; 23: 814-21.

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