JOURNAL OF HEALTH AND SOCIAL SCIENCES

Journal of Health and Social Sciences (JHSS)
The Italian Journal for Interdisciplinary Health and Social Development *EDIZIONI FS Publishers*

Original Article in Orthopedy and Rehabilitation

Investigating the effects of knee valgus orthosis on knee joint contact forces among subjects with knee osteoarthritis: A case series study

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Abstract

Introduction: An increase in knee joint loading exacerbates the symptoms of knee joint osteoarthritis (OA). One of the conservative treatments used for subjects with knee OA is knee valgus orthosis, which is used to decrease the loads on knee joints. The aim of this study was to determine the effects of a new design of knee orthosis on joint contact force and muscle force in subjects with knee OA.

Methods: Ten subjects with knee OA were recruited for this study. A motion analysis system with seven high-speed cameras and a Kistler force plate were used to record the motion of the subjects in walking and the forces applied on the leg. We used OpenSIM software to determine the knee joint contact force during walking, with and without the orthosis.

Results: The knee orthosis decreased the peaks of the vertical component of knee joint contact forces ($p < 0.05$). Moreover, it did not influence walking speed. The use of the orthosis decreased the extension moment of the knee joint and the peaks of the forces produced by the muscles surrounding the knee joint.

Discussion: The use of this orthosis decreased the knee joint contact forces. This suggests that the orthosis could be used to alleviate the symptoms of knee OA. Orthosis can be incorporated into the clinical management of subjects with knee OA by medical practitioners.

Take-home message: The study demonstrated that the new design of knee orthosis effectively reduces the knee joint contact and muscle forces in subjects with knee osteoarthritis without affecting walking speed. These suggest that orthosis could be a valuable conservative treatment option to alleviate symptoms and manage knee osteoarthritis in clinical practice.

Keywords: Knee; orthosis; osteoarthritis; rehabilitation.

Cite this paper as: Karimi MT, Bahramizadeh M, Khaliliyan H, Ansari M, Batra K, Afolabi A, Ilesanmi O, Szarpak L, Khabbache H, Nucera G, Sitibondo A, Ghaffari F, Sharafatvaziri A, Chirico F. Investigating the effects of knee valgus orthosis on knee joint contact forces among subjects with knee osteoarthritis: A case series study. J Health Soc Sci. 2024;9(2):190-200. Doi: 10.19204/2024/NVST2.

Received: 02 March 2024; Accepted: 08 June 2024; Published: 15 June 2024

INTRODUCTION

Osteoarthritis (OA) is a common degenerative joint disease among elderly population with the knee joints experiencing more frequent involvement than other lower limb joints [1,2]. Researchers report a higher rate of involvement in both knee joints, with a greater involvement of the right knee compared to the left knee [3]. The knee joint plays a crucial role in absorbing force and maintaining balance while walking [4, 5]. Therefore, knee OA is one of the leading causes of disability, pain, reduced range of joint movements, and joint instability (which may increase the risk of falling) [6-8]. After the age of 60 years, 85% of the population exhibits radiological signs of OA [9]. This condition has a significant negative impact on patient's quality of life, reducing their ability to work and engage in recreational or daily activities [10]. Additionally, it has substantial financial and social adverse effects [11].

Studies have shown that the involvement rate of the medial compartment of the knee is 5 to 10 times higher than that of the lateral compartment. Walking applies more mechanical pressure to the medial compartment [12-15]. Normally, when walking, the ground reaction force passes through the medial side of the knee and creates an adductor arm around this joint throughout the stance phase. Patients with knee OA often attribute the high prevalence of medial compartment OA to the presence of the knee adductor moment and the resulting increase in load on the medial compartment [16].

It has also been observed that knee adduction moment is the primary determinant of the loads applied on the medial side of the knee joint which is twice times higher than that on the lateral side [17]. Researchers have utilized various treatment approaches to alleviate the symptoms of knee OA and enhance the standing and walking performance of these subjects. These approaches include surgery (wedge osteotomy and arthroplasty) [18] and conservative treatment (physical therapy exercise and use of a valgus brace) [19-22]. Moreover, subjects with knee OA adopt some strategies to decrease the loads applied to the knee joint [23, 24].

Knee braces, such as the Generation II brace, Medial unloading Monarch brace, and Vista CA brace, have been used to improve the knee joint's alignment and decrease the loads on it [25-27]. It has been shown that the use of knee orthoses reduces the adduction moment of the knee joint (which is the main indicator of the loads applied to the knee) and reduces knee pain while walking [25]. Another valgus orthosis was designed by Karimi et al. with a modular structure and the ability to change the alignment of the components relative to each other based on patients' needs [27].

In previous studies, the efficiency of orthoses in decreasing the loads on the knee joint was determined based on the magnitude of adduction moments, which is claimed to be an important proxy of knee loads [28, 29]. However, to date, the knee joint contact force during walking with a knee brace in subjects with OA has not been examined. A preliminary study on five subjects with knee OA with fewer parameters than the present study reported that the loads applied to the knee joint decreased following the orthosis [30]. To the best of the authors' knowledge, there is limited knowledge on the evaluation of joint contact and muscle forces on a large number of subjects with knee OA. Therefore, the aim of this study was to investigate the effect of orthosis on the magnitude of knee joint contact and muscle forces in subjects with knee OA. This study is based on the premise that knee orthosis would significantly decrease knee joint contact and muscular force in subjects with knee OA.

METHODS

Study design

This is a case series study in which we used a pre-post design. Participants completed walking trials both with and without the orthosis, and we analyzed the outcomes to assess the impact of the orthosis on knee joint biomechanics.

Study setting

This study was conducted on individuals with knee osteoarthritis (OA). Table 1 presents the characteristics of the subjects who participated in this study. The Technical Orthopaedic Clinic of the Rehabilitation School at Shiraz University of Medical Sciences was selected as the location for both sampling and intervention construction. We employed the convenience sampling method to select the participants.

Table 1. Characteristics of the sample (N=10)

	Mass (kg)	Height (m)	Age (year)
Mean ± SD	53.37±3.02	1.568±0.065	72.45±3.7

Eligibility criteria

The severity of knee OA was determined according to the American College of Rheumatology criteria for diagnosis of OA, which include medial knee pain and radiographic osteophytes in the medial side of the knee joint. The severity of OA was determined by Kellgren and Lawrence grade (K-L). Conditions such as varicose veins and other conditions that impact walking patterns, recent knee injuries, diagnosed neurological disorders, knee ligament issues and meniscal tears, a history of rheumatic diseases in the lower limbs, foot wounds and neuropathy, joint infections, diabetes, and the use of walking aids were the exclusion criteria in this study.

Measures

We used a Kistler force plate to measure the force on the leg during walking with and without an orthosis. A motion analysis system (Qualysis with 7 high-speed cameras) was used to record the body's motions. The study examined the following parameters: force applied to the leg during walking, knee joint contact forces, spatiotemporal gait parameters, muscle forces, and the ranges of motion of the knee, hip, and ankle joints.

Procedure

We attached 22 reflective markers with 14 mm diameters to the following anatomical landmarks: the lateral and medial sides of the knee and ankle joints, the first and fifth metatarsal heads, the heels on the right and left sides, the sternum, the top of the head, the sacrum, and the left and right acromioclavicular joints. In addition, we attached four marker clusters to the anterolateral surfaces of the thighs and shanks on the right and left sides. The subjects walked with and without the orthosis, and five successful trials were assessed. The data were recorded at a frequency of 100 Hz and filtered with a Butterworth low pass filter at a cut off frequency of 10 Hz.

The knee valgus orthosis has been previously described in literature (Figure 1) [27]. From Figure 1, the knee orthosis consisted of shank and thigh shells with an adjustable polycentric knee joint. The knee joint of the orthosis could be adjusted in the frontal plane to change the alignment of the knee joint in the mediolateral direction. Moreover, there were two pads inside the upper lateral and lower medial parts of shank shell (the forces of the pads could be modified using special screws).

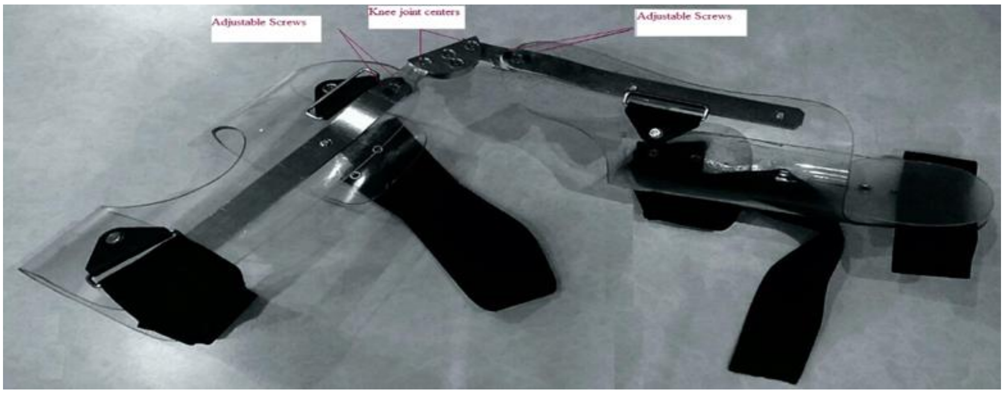

Figure 1. The knee orthosis used in this study.

We labelled all markers and exported them as 3D to Mokka software. We used Mokka software to convert the 3D format into Trc, and OpenSIM software to determine the kinematics and moments of knee joints, and the force applied to the knee joint [33]. Figure 2 shows the flowchart of the procedure used in this study. We performed the scaling procedure in OpenSIM with an error of less than 3 cm for all subjects. For inverse kinematics, the model's error was less than 2 cm.

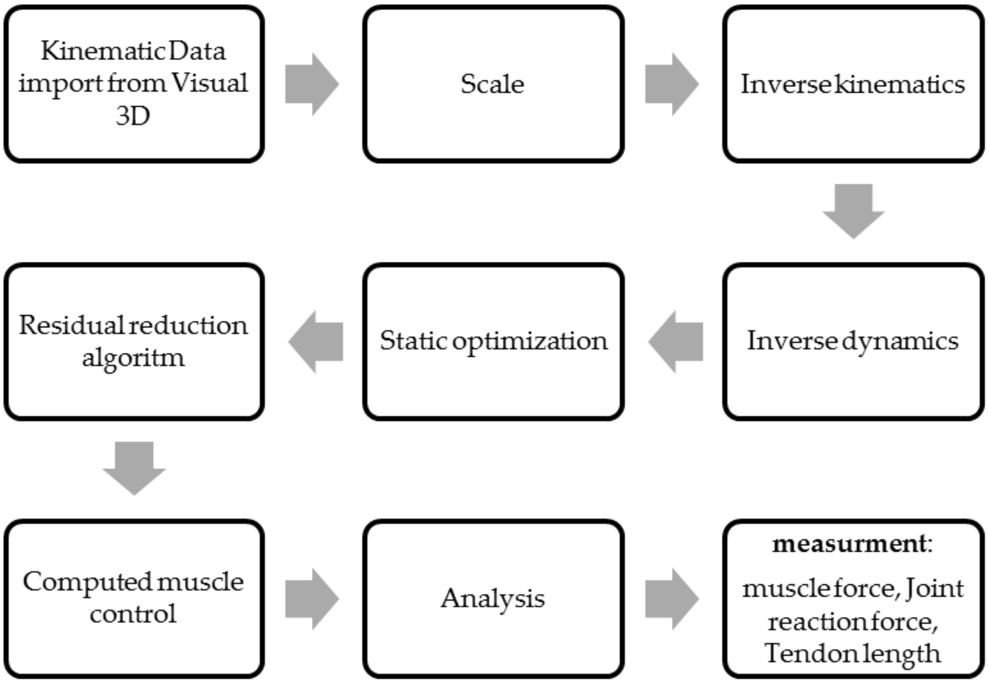

Figure 2. The procedures of OpenSIM software used to determine joint contact force analysis.

We conducted test of normality using the Shapiro- Wilk tests to examine the distribution of the continuous variables used in this study. Since Shapiro- Wilk test revealed that the parameters had a normal distribution ($p > 0.05$), a paired t-test was used to compare the two sets of data. We set the significance value at p-value < 0.05.

Ethical aspects

This study was conducted in accordance with the Declaration of Helsinki. The Ethics Committee of Shiraz University of Medical Sciences approved this study (IR.SUMS.REHAB.REC.1397.019). Before data collection, we obtained written informed consent from each eligible participant.

RESULTS

The mean values of walking speed with and without orthosis were 48.94± 9.20 and 47.68±8.51 (m/min), respectively ($p = 0.36$). There was no difference between stride length and cadence of the OA subjects while walking with and without the knee orthosis ($p > 0.05$). Table 2 shows the mean values of spatiotemporal gait parameters during walking with, and without orthosis.

Table 2. Comparing mean and standard deviation of spatiotemporal gait parameters (N=10).

Variable(s)	Without orthosis	With orthosis	P-value
Velocity (m/min)	47.68±8.51	48.94±9.2	0.36
Cadence (steps/min)	102.78±32.08	107.89±32.4	0.15
Stride length (m)	0.94±0.28	0.96±0.23	0.26

The magnitude of ground reaction force components in the two conditions is shown in Table 3. There was no significant difference between the forces applied to the leg in the two conditions (p-value>0.05).

Table 3. Comparing mean and standard deviation of ground reaction force comments while walking with and without orthosis (N=10).

Variable (s)	Without orthosis	With orthosis	p- value
GRF vertical (1th peak) (N/BW)	0.98±0.12	1.007±0.09	0.19
GRF vertical (2th peak) (N/BW)	1.03±0.12	1.002±0.14	0.17
GRF anteroposterior (1th peak) (N/BW)	0.105±0.04	0.11±0.04	0.11
GRF anteroposterior (2th peak) (N/BW)	0.13±0.05	0.12±0.04	0.41
GRF mediolateral (N/BW)	0.04±0.02	0.036±0.02	0.21

Note: GRF: Ground Reaction Force, N: Newton, BW: Body weight

The moments applied to the leg were the other parameters evaluated in this study. The mean values of the extension moment during walking with and without orthosis were 0.015±0.010 and 0.019±0.020 Nm/kg, respectively. Although the mean values of extension moment during walking with the orthosis decreased, the difference was not statistically significant. There was no difference between the range of motion of the knee joint in the sagittal plane during walking with and without orthosis (Table 4).

Table 4. Comparing mean and standard deviation of a range of motion and sagittal plane moments of the knee joint (N=10).

Variable (s)	Without orthosis	With orthosis	p-value
Extension moment (N.m/Kg)	0.019±0.02	0.015±0.01	0.026*
Flexion moment (N.m/Kg)	0.02±0.0201	0.018±0.01	0.4
Knee ROM (degree)	56.9±14.2	55.06±7.5	0.28

Note: N: Newton; m: meter; ROM: Range of Motion

The first peaks of knee joint contact force in the vertical direction were 2.970±0.390 N/BW and 2.540±0.380 N/BW, during walking with and without the orthosis, respectively (p = 0.03). Table 5 shows a summary of the mean values of joint contact force components.

Table 5. Comparing mean and standard deviation of knee joint contact force components while walking with and without the orthosis (N=10).

Variable (s)	Without orthosis	With orthosis	p-value
JCF anteroposterior (N/BW)	0.885±0.24	1.01±0.5	0.18
JCF vertical (1th peak) (N/BW)	2.97±0.39	2.54±0.38	0.03*
JCF vertical (2th peak) (N/BW)	3.2±0.68	2.61±0.46	0.01*
JCF mediolateral (N/BW)	0.242±0.08	0.22±0.37	0.25

Note: JCF: Joint Contact Force

The peaks of muscle forces surrounding the knee joint were also evaluated in this study. From Table 6, the forces produced by knee muscles decreased following the use of orthosis; however, for most of the muscles, the differences were not significant (p-value>0.05).

Table 6. Comparing mean and standard deviation of peaks of knee muscles forces while walking with and without knee orthosis (N=10).

Parameters	Without orthosis	With orthosis	p-value
Lateral head of Gastrocnemius	0.33± 0.12	0.28±0.9	0.19
Medial head of Gastrocnemius	0.97± 0.3	0.75± 0.28	0.06
Vastus lateralis	0.39± 0.21	0.41± 0.11	0.38
Vastus Intermediate	0.24± 0.13	0.25± 0.06	0.38
Vastus Medialis	0.18±0.09	0.19± 0.05	0.4
Rectus femoris	0.55± 0.17	0.59± 0.25	0.26
Gracilis	0.02± 0.01	0.015± 0.008	0.04
Biceps (Long Head)	0.35± 0.12	0.28± 0.1	0.08
Biceps (Short Head)	0.4± 0.22	0.33± 0.19	0.22
Semitendinosus	0.12± 0.04	0.09± 0.04	0.1
Semimembranosus	0.56±0.02	0.48±0.025	0.13

DISCUSSION

This study aimed to evaluate the effect of a newly designed knee valgus orthosis on knee joint contact force in patients with knee OA. Our current study results showed that the spatiotemporal gait parameters and the mean values of the force applied to the leg did not differ significantly while the subjects were walking with or without orthosis. These findings, therefore, imply that orthosis did not restrict the subjects' abilities [35-38]. Lack of symptomatic relief, brace discomfort, poor fit, and skin irritation are some issues associated with other knee orthoses [35]. As the orthosis did not influence walking speed, it is possible that subjects did not experience the problems mentioned above.

The mean values of the first and second peaks of knee joint contact force decreased significantly when the knee orthosis was used. It should be noted that the joint contact force is a combination of external forces (ground reaction force, muscular force surrounding the knee joint, and supportive ligaments) [39, 40]. As the force transmitted through the legs did not decrease with the use of the orthosis, a reduction in knee joint contact force may be mostly due to a change in the performance of the muscles surrounding the knee joint.

In individuals with knee OA, spatiotemporal variables were decreased to lower knee adductor moment, which could help alleviate pain [13, 14]. Decreased speed is an adaptive mechanism employed by individuals to minimize moments on the knee joint [12]. This study did not alter the spatiotemporal variables, but it is believed that the desired joint has experienced improved moments.

In OA subjects, there are some theories about the load distributions on the knee joint. Based on Condylar-lift-off theory, the main problem in subjects with OA in the medial compartment is lateral joint opening, which can be delayed by increasing the compressive forces at the knee [41, 42]. Therefore, these subjects would need to increase the contraction of the quadriceps to increase the compressive force to stabilize the knee joint [12-14]. The results of this study also indicate that the use of knee orthosis stabilized the knee joint and reduced knee space on the lateral side. As a result, subjects with knee OA may require less compressive force to stabilize the knee joint. This means that the mean values of knee flexion and extension moments decreased simultaneously.

The moments of the knee joint decreased following the use of the orthosis. This suggests that subjects did not use more compressive force to stabilize the knee joint. The reduction in force of the muscles surrounding the knee joint is good evidence of the stability the knee orthosis provides [27]. This means the subjects did not need to dynamically stabilize the knee joint.

Although the study results indicated the positive effect of knee orthosis on decreasing joint contact force, there are some limitations. The main limitation of this study was the lack of follow-up duration, as the immediate effect of orthosis was evaluated. Hence, the long-term impact of the orthosis is unknown. We had arranged to collect the data of the subjects after two months of use of orthosis; however, due to the COVID-19 pandemic and the restrictions applied, it was impossible to collect the data after a follow-up period. This means that none of the participants were available to collect for the second round of the follow-up. Considering that knee OA is a chronic condition, future studies would be required to determine the effects of the orthosis on these parameters during walking. In addition, the subjects included in the study had less variation in the severity of OA.

CONCLUSION

The findings of this study indicated that the peak of vertical components of joint contact force decreased after knee orthoses were used. We may attribute this decrease to reducing the moments and muscular forces required to stabilize the knee joint. These findings suggest that the orthosis could alleviate knee OA symptoms. Clinicians should take note of the study's findings, as incorporating orthosis into the management of patients with knee OA could be beneficial.

Author Contributions: Conceptualization: MK; methodology: MB, MK; validation: MB; formal analysis: MK; investigation: MK; resources: MB, HK; data curation: MK; writing—original draft preparation: MK, MB, HK; writing—review and editing: KB, MA, AA, OI, LS, HK, GN, FG, AS, FC; supervision: MB. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement: This research approved by Shiraz University of Medical Sciences Ethics Committee (Code: IR.SUMS.REHAB.REC.1397.019).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Acknowledgements: None

Conflicts of Interest: The authors declare no conflict of interest.

Publisher's Note: Edizioni FS stays neutral with regard to jurisdictional claims in published maps and institutional affiliation.

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