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Toe-in Gait, Associated Complications, and Available Conservative Treatments: A Systematic Review of Literature

Mohammad Taghi Karimi

Department of Orthotics and Prosthetics, Faculty of Rehabilitation, Shiraz University of Medical Sciences, Shiraz, Iran

Purpose: Toe-in gait is defined as a style of walking in which the foot turns inward. It may be caused by an increase in femoral bone anteversion, tibia torsion, and metatarsus adductus. There are some conservative treatment approaches used to correct this condition. This review aimed to determine the effects of the toe-in gait on joint loading, kinematics, and kinetic parameters while walking. Moreover, it sought to determine the efficiency of various conservative treatments used to correct the condition.

Materials and Methods: A literature search was conducted in the following databases: PubMed, Institute for Scientific Information (ISI), Web of Science database, EBSCO, and Embase, using the following keywords in toe, toe-in, toeing, in-toe, pigeon toe, and conservative treatment published between 1950 and 2021. The quality of the studies was evaluated using the Down and Black tool.

Results: A total of 13 papers on the impact of toe-in gait on joint contact force, kinematics, kinetic parameters, and conservative approaches to management were found. The quality of the studies varied between a score of 11 and 22. The toe-in gait influences the joint contact forces and kinematics of the joints, especially the hip and pelvis. The effects of conservative treatment on the toe-in gait appear to be controversial.

Conclusion: As the toe-in gait influences the joint contact force, it may increase the incidence of degenerative joint diseases. Therefore, treatment is recommended. However, there is no strong evidence on the efficacy of conservative treatments, and there are no recommendations for the use of these treatments in subjects with toe-in gait.

Key Words: Toe in gait, Joint contact force, Kinetics, Kinematics, Conservative treatment

INTRODUCTION

Toe-in gait or pigeon gait is defined as a walking style in which the child walks or runs and turns the foot inward instead of pointing straight ahead.[1,2] It may be due to various reasons such as metatarsus adductus (foot turns inward), tibia torsion (shank turns inward), and femoral anteversion (femur turns inward). In this disease, the angle between the femoral neck and condyle is more than 16 degrees at age of 5 years.[3] The incidence of this disease is a source of doubt and most of time requires no treatment and decreases throughout the growth period.[4,5] Blackmur and Murray[6] reported that in 2010, 3% of children in Scotland with toe-in gait pattern were referred to pediatric orthopedic surgeons to achieve treatment.

There may be two reasons regarding the treatment of the subjects with toe-in gait. Some clinicians treat this deformity only for cosmetic reasons. In contrast, others try to decrease the deformity due to its side effects on other joints. Recent literature has confirmed the association of excessive femoral anteversion with femoral acetabular impingement, lateral tear, and anterior knee pain due to patella-femoral malalignment.[7] It was claimed that an increase in the anteversion of the femur increases the mal-function of the hip joint which finally increases the incidence of hip joint osteoarthritis.[8] In contrast, it was also claimed that toe-in gait increases the plantar flexion moment of the gastro-soleus muscle during push-off and increases the performance of the subjects during walking. It was shown that most of runners have some

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Corresponding Author: Mohammad Taghi Karimi
Department of Orthotics and Prosthetics, Faculty of Rehabilitation, Shiraz University of Medical Sciences, Shiraz 7194733669, Iran
Tel: 98-71362589558, Fax: 98-71036272495, E-mail: Mt_karimi@sums.ac.ir
ORCID: https://orcid.org/0000-0001-6162-8131

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degree of toe-in gait without any effects on other joints and structures. Therefore, the first question posted here is what are the influences of toe-in gait on standing and walking performance? And also Dose it influence the loads applied on the other joints or not?

Although various treatment approaches have been used for the subjects with toe-in gait, they can be divided into conservative treatment approaches and surgery.[9] Orthopedic shoes with special modifications, night splints, Dennis-Brown splint, twister cables, Thera Togs, and Ground Reaction Foot Orthosis are some of the conservative treatment recommended for subjects with toe-in gait.[9] Physical therapy is the other conservative treatments approach recommended to be used for the subjects with toe-in gait.[10] As some of the internal and external hip rotators in the subjects with toe-in gait are distributed, stretching of external rotator muscles may reduce the foot progression angle (FPA) and decrease toe-in gait. portable microcurrent therapy device (PMTD) is the other treatment approach used to stimulate the external rotator muscle during walking.[10]

This review article aimed to evaluate the effects of toe-in gait on walking parameters. Moreover, it was aimed to determine the efficiency of various conservative treatment approaches used for the subjects with toe-in gait based on the available literature.

MATERIALS AND METHODS

A search was done in some databases including PubMed, ISI web of knowledge, Google Scholar, Ebsco, Embase, and Scopus. The following search terms were selected based on some keywords include: in toe, toe-in, toeing, in-toe, and pigeon toe in a period between 1950 and 2021. Criteria used to select the papers were based on titles and abstracts to address the research questions of interest. Specific selection criteria were as follows:

Study design: The review intended to include children with toe-in gait, aged less than 15, and mostly due to anteversion angle. Therefore, the papers on toe-in gait due to some diseases such as knee osteoarthritis were excluded from the review study.

Intervention: The main intervention considered in this review study was conservative treatment including orthoses, physical therapy, and exercise. Therefore, the studies on surgery and its influence on toe-in gait were excluded from the final list.

Outcome measures: The main outcome measures included in this study were joint contact force, kinematic and ground reaction force. For the second aim (effects of conservative treatment on toe-in gait) some parameters such as FPA, and anteversion angle of femur were selected.

Secondary outcomes: Any adverse effects of using various interventions reported in the included studies were considered secondary outcomes.

Selection of the studies: Two researchers determined the suitability of the papers based on the inclusion criteria. This was done mostly based on abstracts and titles. If there was any disagreement, a third researcher was enrolled.

Data extraction and management: Data extraction in this review was based on the PICO style (population, intervention,

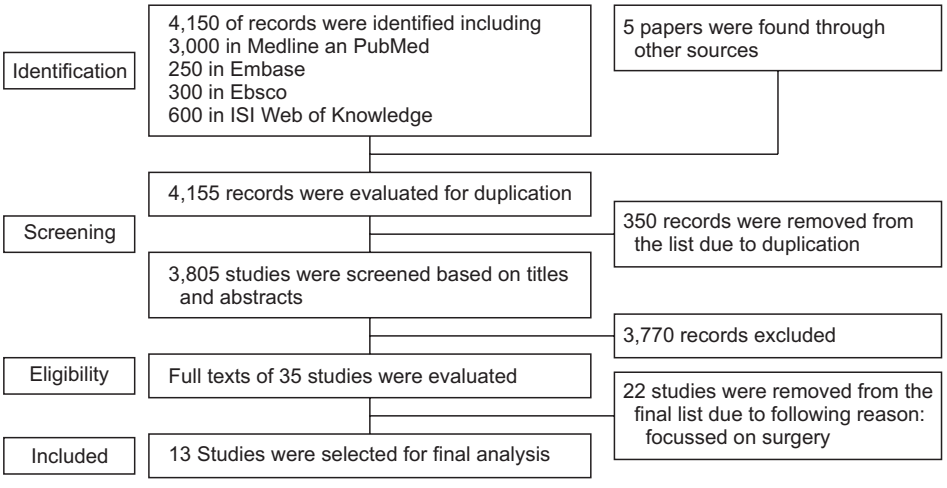

Figure 1. The procedure used to select the studies in this review article.

comparison, and outcomes). Duration of follow-up, outcome assessment and any adverse effect of treatment were also reported.

Quality assessment and determination of the risk of bias: Down & Black tool was used to determine the quality of the selected studies. This tool has a high degree of validity and reliability which determine the bias of the studies.

The outputs of the selected studies and their methods were summarized based on the PICO style (Population, intervention, comparison, and outcomes). Fig. 1 shows the procedure used in this study.

RESULTS

Based on the mentioned keywords, 35 papers were found on this topic. Based on inclusion criteria, finally, 13 papers were selected. There were 10 papers on the effects of toe-in gait on the joint contact forces, kinematic, kinetic, and, gait performance (with quality varied between 13 and 18). However, it should be emphasized that most of these studies were on cerebral palsy subjects. There was one study on the finite element analysis, 2 on electromyograph activities of the muscles, 1 paper on balance, 5 on gait analysis, and only 1 paper on the effect of anteversion correction on energy consumption. The results of these studies confirmed the following points:

1. Pelvis compensates femoral anteversion.[11]
2. Toe-in gait is not only a cosmetic problem, as it influences the kinetic and kinematic parameters.[12]
3. An increase in femoral anteversion angle is associated with reduced dynamic control in frontal and transverse planes of hip and patella-femoral joints.[13]
4. Proximal deformity mainly affects sagittal plane muscle control.[14]
5. Femoral anteversion does not influence functional balance.[15]
6. In cerebral palsy patients, femoral anteversion mostly correlates with tibia torsion.[16]
7. Loading of the proximal part of the femur mostly correlates with the anteversion of the femur.[17,18]
8. Energy consumption decreases after de-rotational surgery.[19]

There were 3 studies on treatment approaches (conservative treatment) used for the subjects with toe-in gait. The quality of these studies was low due to the limited number of participants, the short follow-up period, and also due to no attempt was done to blind the researchers and participants regarding the interventions, Table 1.[20-22] Only one study was on the use of PMTD in subjects with toe-in gait. The outputs of these studies highlighted the following points (Tables 2, 3):

Table 1. The Effects of Various Conservative Treatments on Toe-in Gait Deformity

Reference	Method	Result
Schumacher et al., 2018[22]	Patients: 11 subjects with toe-in gait (Mean age: 10.4±1.6 years) Intervention: Portable microcurrent therapy device (PMTD) to stimulate hip internal rotation Comparison: The ranges of hip internal and external rotation	Hip internal rotation angle before treatment and after treatment were 70.3±5.4 and 55.7±7.8 degrees, respectively. Hip external rotation angles were 20.1±5.5 and 33.6±8.2 degrees before and after treatment. The results of this study showed that PMTD may have the potential to improve the gait pattern in children with toe-in gait.
Redmond, 1998[20]	Patients: 18 children with toe-in gait Intervention: Gait plate Comparison: The foot placement angle was measured in this study. Moreover, a simple questionnaire was used to determine parental satisfaction.	The reported results also showed that parental satisfaction was high or very high. There was a significant negative correlation between the foot progression angle at diagnosis and the subsequent improvement.
Ehlert et al, 2017[21]	Patients: 57 children of both sexes aged between 6 and 8 years participated in this study. They were divided in to three groups: - Group A: training program without any orthotic management - Group B: training program with Thera Togs - Group C: only Thera Togs with static ground reaction AFO Intervention: training and Thera Togs orthosis Comparison: Gait speed, cadence, stride length, hip and knee flexion angles	Significant difference was recorded amongst the three groups in gait speed, cadence and stride length. For all measurement significant results were obtained for group C than other groups.

Table 2. The Results of the Studies on the Effects of Increase in Femoral Anteversion Angle on Joints Loading, Kinetic and Kinematic Parameters

Reference	Method	Result
Radler et al., 2010[11]	Patients: 26 subjects with toe-in gait Intervention: None Comparison: ROM of pelvis and hip joint, and their correlation with FA	Mean femoral anteversion was 28 degrees, mean tibia torsion was 28 degrees (external rotation). High correlation exists between pelvis ROM and femoral anteversion which reports the role of pelvis to be involved as a compensatory mechanism. But there was a weak correlation between FA and hip rotation.
Bruderer-Hofstette et al., 2015[12]	Patients: 18 subjects with toe-in gait (10.5~17.5 years) and 17 normal subjects (10.6~17.3 years) Intervention: None Comparison: Kinematic and kinetic parameters while walking. Principle component analysis (PCA) was performed using MATLAB.	The mean of anteversion angle based on CT-scan was 38.9 degrees. The patients had more anterior pelvic tilt than control, patients had more hip flexion angle and less hip extension angle compared to control. Foot external rotation in patients is less than control group. Anteversion is not just a cosmetic problem as modification in kinematic and kinetic may be associated with future physical problems or even osteoarthritis.
Nyland et al., 2004[13]	Patients: 18 normal female Intervention: Resistance belt (push up and out against resistance) Comparison: EMG was recorded from tensor fascia lata, gluteus medius and maximus and vastus medialis.	For the subjects with increased anteversion angle (medial hip rotation >42 degrees) there was a 34% decrease in mean peak gluteus medius EMG amplitude and 27% decrease in mean peak of vastus medialis. It seems that increase in femoral anteversion angle is associated with reduced dynamic control of hip and patellofemoral joints in frontal and transverse planes.
Naseri el al, 2020[24]	Patients: 7 diplegic CP (aged between 8~12 years with aberrant femoral geometry [FA 23~56 degrees], with neck shaft angle [NSA] between 133 and 157 degrees) Intervention: None Comparison: joint angle, joint moments normalized and potential joint angular acceleration	All children walked with increased hip and knee flexion angle throughout the gait cycle, indicating crouch gait. This study supported the effects of proximal femoral deformity and CP gait characteristics on control of hip, knee joint kinematics during CP-gait. Proximal deformity mainly affects sagittal plane muscle control. The compensatory mechanism in pathologic gait may influence joint loading.
Cimolin et al., 2010[25]	Patients: 23 CP diplegic children (5~13 years, mean 9.27 years), and control group = 15 healthy subjects (5~16 years) Intervention: None Comparison: Gait analysis and EMG of leg muscles CP subjects were divided into groups: Those with increase in femoral anteversion without Rectus Femoris spasticity and those with normal anteversion with Rectus Femoris spasticity	Those with increase in femoral anteversion exhibited a reduced value of KMSW parameter with excessive hip internal rotation. Spasticity of Rectus Femoris reduced peak of knee flexion in swing with delay in its timing with hip rotation closed to normative data.

ROM: range of motion, FA: femural anteversion, CP: cerebral palsy, EMG: electromyograph, KMSW: knee moment slow walking.

1) PMTD may have the potential to improve the gait pattern in children with toe-in gait[10]
2) The children's parents showed high satisfaction with the use of the gait plate[20]
3) The use of Thera Togs with static ground reaction ankle foot orthosis (AFO) improves gait speed, cadence, and stride length, and increases hip and knee flexion angles.[23]

DISCUSSION

In this review study, it was found that toe-in gait influences the kinematic of the hip and pelvis. Although it does not influence dynamic stability while walking, it may increase joint contact forces which finally increases the incidence of degenerative joint diseases (DJD). Based on the search done in various databases, there were 10 studies on this topic, with quality varied between 13 and 18 (Table 4). However, it should be emphasized that the number of subjects in most of these studies was too limited and some of these studies were done based on a modeling approach. Based on the results of the gait analysis, femoral anteversion influences the kinematic and kinetic parameters while walking.[11,24,25] However, it should be emphasized that it influences mostly

Table 3. The Results of the Studies on the Effects of Increase in Femoral Anteversion Angle on Joints Loading, Kinetic and Kinematic Parameters

Reference	Method	Result
Karabicak et al., 2016[15]	Patients: 12 subjects with CP (spastic CP diagnosis only right side; age, 5~8 years) Intervention: None Comparison: Functional balance was evaluated with pediatric balance scale Postural control was evaluated based on trunk control while sitting	The results of this study confirmed the correlation between FA and dynamic reaching. No correlation between FA with functional balance, control of the trunk and static sitting balance. The results confirmed that FA dose not correlate with functional balance, static sitting and selective control of trunk.
Carriero et al., 2009[16]	Patients: 9 children with spastic diplegic CP (aged between 6~12 years). There was also a control group of 10 healthy children (6~13 years) Intervention: None Comparison: Morphological characteristic of bone was determined based on MRI. Morphological parameters include: bio-condylar angle, neck-shaft angle, anteversion angle and tibia torsion. Kinematic parameters determined based on gait analysis.	In healthy children, hip adduction correlated with neck-shaft and bio-condylar angle. In CP pelvic obliquity correlated with neck-shaft angle and foot rotation with bio-condylar angle. In transverse plane, hip and pelvic rotational kinematics related to femoral anteversion in healthy and to tibial torsion in CP.
Heller et al., 2001[18]	Patients: 4 total hip arthroplasty patients with telemetric prostheses (11~31 months postoperatively) Intervention: None Comparison: Joint contact forces were determined during level walking and stair climbing	Good agreement between hip contact forces calculated experimentally and numerically. Increase anteversion to an angle of 30 degrees increased hip contact forces and bending moment to 27%. Loading of proximal part of femur depends on anteversion of femur.
Carriero et al., 2011[17]	Patients: No participant, FE model was used Intervention: Change in morphology of femur and change in Coxa valga angle Comparison: Joint loading	Understanding the role of loading in skeletal morphologic prevents bone deformities and improves function in children with gait deformities.
Amichai et al., 2009[19]	Patients: 18 CP subjects participated in this study (aged between 6 and 11 years). Intervention: Corrective surgery Comparison: Energy consumption of stair climbing was assessed. Functional walking was assessed using the FAQ scale Participants were assessed 3 times: 1 day before surgery, 6 months after surgery and 1 year after surgery. Range of motion of hip was evaluated in prone position	Hip range of rotation improved after surgery. Moreover, energy consumption decreased after surgery. Therefore, it was conducted that CP patients may benefit from femoral de-rotation surgery.

CP: cerebral palsy, FA: femural anteversion, FE: finite element, FAQ: Functional Assessment Questionnaire.

Table 4. The Results of Quality Assessment of the Included Studies

Article	Level of evidence	Reporting	External validity	Internal validity (bias)	Internal validity (confounding)	Total score
Ahn et al., 2017[10]	3	8	2	5	2	17
Radler et al., 2010[11]	3	7	0	5	2	14
Bosmans et al, 2016[14]	4	5	1	4	2	13
Cimolin et al., 2010[25]	4	8	2	5	1	16
Heller et al., 2001[18]	3	5	0	5	1	11
Redmond, 1998[20]	2	5	2	5	2	14
Abd, 2014[23]	1	9	2	7	4	22
Bruderer-Hofstetter et al., 2015[12]	4	8	1	5	1	15
Nyland et al., 2004[13]	4	7	0	4	3	14
Karabicak et al., 2016[15]	3	8	2	5	3	18
Carriero et al., 2009[16]	3	7	0	5	1	13
Carriero et al., 2011[17]	4	5	0	5	2	12
Amichai et al., 2009[19]	3	8	2	4	2	16

the pattern of motion of pelvic and also tibia torsion.[11] Any change in the range of motion (ROM) of the joint and its pattern will influence the loads applied to the joints. The results of the study done by Heller et al also support an association between anteversion of the femur and loading of the proximal part of the femur.[18] This study was done based on motion analysis and also a modeling approach. Based on all available studies it can be conducted that an increase in femoral head anteversion is associated with kinematic changes in other joints. These kinematic changes mostly occur as compensatory mechanisms which finally increase joint contact forces. Based on the results of some studies, there is a correlation between an increase in joint contact force and DJD.[26,27] Therefore, it seems that treatment of anteversion should be done to decrease DJD. Unfortunately, there is no study in the literature, in which the subjects with toe-in gait were followed for a longer period of time.

Based on the results of the available literature, there were very limited shreds of evidence on the efficiency of various conservative treatments used for the subjects with toe-in gait. There were only 3 studies with low quality, Table 4. There was only one study on the efficiency of stimulation of the hip internal and external rotator muscles on the gait pattern of the subjects with toe-in gait. The quality of this study was low. However, the output of this study showed that the PMTD may have the potential to improve the gait pattern in the subjects with toe-in gait.[10] However, it should be emphasized that in this study the ROM of the hip joint was recorded to evaluate the efficiency of treatment.

There were two studies on the efficiency of orthoses for subjects with toe-in gait.[20,21] In the first study, the parental satisfaction of the subjects with toe-in gait was evaluated. Based on the results of this study, the level of satisfaction was high or very high regarding the use of a gait plate.[20] In another study done by Abd El-Kafy,[23] 57 children with toe-in gait participated. They used various interventions including a training program without any orthotic management, a training program with Thera Togs, and Thera Togs with static ground reaction AFO. The results of this study showed that cadence, stride length and gait speed increased significantly for the third group than other groups.[23] However, there was no result regarding the effects of this type of intervention on the correction of femoral anteversion angles and FPA. Although the quality of this study is relatively high they evaluated only some simple parameters. Based on the above-mentioned studies, it is not possible to have a strong conclusion on the efficiency of various conservative treatment approaches on the correction of femoral anteversion angle in the subjects with toe-in gait.

There are some limitations with available studies. The main limitation was the lack of studies that followed the subjects with toe-in gait for a long period of time. The other limitation was the limited number of subjects with available studies. Therefore, it is recommended that the efficiency of various orthotic interventions should be evaluated in a study with the big number of subjects with a long duration of follow-up.

CONCLUSION

Based on the available literature and due to the quality of the studies, it can be concluded that an increase in femoral neck anteversion angle may increase the loads applied on the hip joint and also influences the kinematics of the hip and especially pelvis. The change in kinematic of hip and pelvis joints also influenced the compensatory mechanisms which finally lead to an increase in joint contact forces. Based on the available literature it is difficult to have a strong conclusion on the efficiency of available conservative treatments used for the subjects with toe-in gait. It is recommended to do a study on the efficiency of various orthotic interventions for the subjects with toe-in gait.

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