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# 1 Effects of contracture on gait kinematics: a systematic review

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## Abstract

Background: Contractures of a major joint in the lower limbs may impair human walking in addition to other daily living activities. A contracture is defined as the inability of a joint to perform the full range of motion and excessive resistance during passive mobilization of the joint. Few studies have reported methods describing how to evaluate contractures. Understanding the association among all of these studies seems essential to improve patient management. Therefore, we conducted a systematic review on this topic to elucidate the influence of contractures on gait kinematics.

Methods: An electronic search in the literature will be conducted. Studies were screened by title and abstract and full texts were evaluated secondarily for definitive inclusion. The quality of the included studies was assessed independently by the two review authors with the Modified Quality Assessment Checklist. The included studies were separated into three categories: pathological contracture versus healthy controls (descriptive), simulated contracture versus healthy controls (experimental), and pre- and post-kinematics after surgical muscle lengthening (surgery).

Findings: From a total of 4402 references, 112 original articles were selected, and 28 studies were identified in this systematic review. No significant difference between raters was observed on the total score of the Modified Quality Assessment Checklist.

Interpretation: Contractures influence walking depending on the location (muscle) and the contracture level (muscle-tendon length). After giving a definition of contracture, this review identified some contracture alterations, such as plantarflexion, knee flexion and hip flexion contractures, with a kinematic description and presented possible different compensations.

**Keywords**: Systematic review, Contracture, Kinematics, Muscle-tendon length, Muscle shortening, Gait

## 1. Introduction

A contracture is defined as the inability of a joint to perform the full range of motion and excessive resistance during passive mobilization of the joint (Gaudreault et al., 2009). The structures involved in contractures include ligaments, capsule, tendons and muscles for which the extensibility is limited and the stiffness is increased (Prabhu et al., 2013). Moreover, Perry and Burnfield (2010) differentiate between elastic and rigid contractures. An elastic contracture yields to the forceful stretch of an examiner or body weight, whereas a rigid contracture resists considerable force (stiffness) and is able to support body weight. **Causes of contracture** can be a result of different factors. Generally, a contracture is a common complication of many neurological and musculoskeletal conditions (Prabhu et al., 2013).

Contractures of a major joint in the lower limbs may impair human walking in addition to other daily living activities (Hoang et al., 2014; Prabhu et al., 2013).

Contractures have a high incidence in neurological and orthopedic conditions (Farmer and James, 2001), including ligament and joint capsule shortening, intra-articular adhesions, fibro-fatty tissue proliferation into the joint and muscular shortening (Fox et al., 2000), muscle retraction, tendinous adherence, skin or subcutaneous tissue loss, joint capsule thickening or a combination of these factors (Roberson and Giurintano, 1995). The primary factors that cause suffering from contractures are burns, spinal cord injuries, cerebral palsy, strokes, and advanced age (Hoang et al., 2014). The association among contracture, muscle weakness and spasticity is generally accepted, although it has not been demonstrated scientifically (Hoang et al., 2014).

**The main effect of contractures** is a limitation of joint range of motion resulting from soft tissue stiffness (Hoang et al., 2014), but contractures can also cause pain, sleep disturbances, pressure ulcers, and deformities (Fox et al., 2000; Prabhu et al., 2013). A limited range of motion affects mobility and daily life activities. Among these activities, walking is a **primordial activity of daily living**. Patients and therapists ranked “moving around indoors” as the most important activity to preserve/restore in patients (Chiou and Burnett, 1985). Contractures induce gait deviations and limit a person’s ability to walk (Hoang et al., 2014). In children with Duchenne muscular dystrophy, joint contracture represents the second most often occurring major clinical impairment that results in gait deviations (Gaudreault et al., 2009). In cerebral palsy, the commonest orthopedic deformity is equinus deformity caused by the contracture of the triceps surae (Galli et al., 2005). To choose the best therapeutic strategy in relation to gait deviations, it is mandatory to understand the gait deviations and to distinguish the primary deviation (directly resulting from the pathology) and the secondary deviation (compensatory mechanisms) (Schmid et al., 2013). Therefore, understanding the effects of contractures on gait deviations is important to support the therapeutic choice. In the literature, different approaches have been used to elucidate the effect of contractures on gait.

The first approach is to compare the gait patterns between persons with contractures and matched healthy persons (Gaudreault et al., 2009; Svehlik et al., 2010). The second approach is to replicate the gait patterns of a patient with contractures by having healthy participants imitate the gait patterns. To this end, the investigators ask the participants to replicate the gait pattern by imitating patients with contractures, e.g., to walk on their tiptoes to imitate a triceps contracture (Romkes and Brunner, 2007). The third approach is to replicate the gait patterns of a patient with contractures in healthy participants by induced constraints. In this case, the healthy participants are constrained in certain joint degrees of freedom with an exoskeleton (Matjacic and Olensek, 2007; Matjacic et al., 2006) or an orthosis (Houx et al., 2012; Houx et al., 2013). The fourth approach is to use a computer simulation to evaluate the effects of constraints induced by contractures on gait (Goldberg and Neptune, 2007; Hicks et al., 2008; Neptune et al., 2007). Finally, the fifth approach is based on the comparison of a patient’s gait before and after treating the contracture (Baddar et al., 2002; Chimera et al., 2012; Galli et al., 2005, 2009; Hemo et al., 2006; Kadhim and Miller, 2014; Lofterod and Terjesen, 2008; Park et al., 2006; Tylkowski et al., 2009). These studies have demonstrated the importance of studying this subject. Associating these studies seems essential to improve patient management. Therefore, we conducted a systematic review on this topic to elucidate the influence of contractures on gait kinematics.

## 2. Methods

### 2.1 Search strategy

To provide a comprehensive overview of the literature, an electronic search will be conducted within the following databases: MEDLINE/PubMed, from January 1948 to July 2014; CINHAL (EBSCO), from January 1981 to July 2014; and EMBASE, from January 1980 to July 2014. In addition, the references of included studies will be searched to identify further studies. The search strategy will encompass the following search terms: contracture, muscle shortening, muscle length, range of motion, joint flexibility, kinematics, biomechanics, walking, gait, and locomotion. The search strategy for the databank MEDLINE will look as follows: #1 (#contracture OR # contracture* OR # muscle shortening OR # muscle length* OR # range of motion OR # joint flexibility); #2 (#kinematics OR # biomechanics); #3 (#walking OR # gait OR # locomotion); and #4 (#1 AND #2 AND #3).

### 2.2 Inclusion and exclusion criteria

Studies were screened by title and abstract following the rules of inclusion and exclusion criteria (Table 1). Full texts were evaluated secondarily for definitive inclusion. Two categories were selected to keep a maximum of articles, embracing concerned fields. The inclusion criteria contained articles about patient and healthy controls, as well as the simulation of contracture by different means. This review also included studies about muscle lengthening surgical intervention; these studies observed the pre- and post-outcome on gait kinematics. Two review authors independently screened the titles and abstracts. Disagreements were resolved by discussion until consensus, and when necessary, a third author arbitrated. Next, reviewers subsequently independently assessed the full-length reports for eligibility of the studies based on the inclusion and exclusion criteria. Disagreements were also discussed and arbitrated by a third author if necessary.

### 2.3 Data extraction and quality assessment

The two review authors independently extracted data from the included studies with a customized form. The following data were extracted: study design or aim, study population characteristics (diagnosis, age, sample size), parameters evaluated (kinematics, kinetics, EMG, etc.), major joints assessed and/or device, and main results (especially kinematics).

The quality of the included studies was assessed independently by the two review authors with the Modified Quality Assessment Checklist (Schmid et al., 2013). The checklist was first described by (Downs and Black, 1998). The authors developed this tool to assess the quality of randomized and non-randomized trials. It has a high internal consistency, good test-retest and inter-rater reliability, and good face and criterion validity. The checklist was modified to assess the quality of non-randomized observational studies (Schmid et al., 2013). The included studies are evaluated with 17 items with a total maximum score of 20 points. These 17 items were then classified in 5 categories and evaluated as follow: reporting quality (8 items, maximum 10 points), external validity (3 items, maximum 3 points), internal validity – bias (3 items, maximum 3 points), internal validity – confounding (2 items, maximum 2 points), and statistical power (1 item, maximum 2 points).

### 2.4 Data Analysis

The extracted data were analyzed in a qualitative manner. The included studies were separated into three categories: pathological contracture versus healthy controls (descriptive), simulated contracture versus healthy controls (experimental), and pre- and post-kinematics after surgical muscle lengthening (surgery). Given that it is difficult to assess the contribution of a single surgery during a multi-level surgery (Lofterod and Terjesen, 2008), we investigated only single surgeries.

An intraclass correlation coefficient (ICC) with (+/- confidence interval) and the p-value (t-test) were calculated to evaluate the inter-rater reliability on the total score of the modified quality assessment. ICC was described according to Shrout and Fleiss (1979) (> 0.75 excellent reliability, 0.4-0.75 fair to good reliability and <0.4 poor reliability). Statistical analyses were performed using MATLAB R2012b (MathWorks, USA).

# 3 Results

## 3.1 Selection of studies

A total of 4402 references were found after the electronic database research. After screening the titles and abstracts and removing duplicates, 112 original articles were selected. Following the request for inclusion and exclusion criteria, 28 studies were identified in this systematic review. The major part of the excluded articles was due: 1) multilevel surgeries (35), 2) absence or inaccurate explanation about contractures (33), 3) absence or incomplete kinematic data (8), 4) letter to editor or commentary (5), 5) abstract (2) and 6) literature review (1). These 28 included studies were then classified in three groups: experimental (15), descriptive (6) and surgery (7). In the experimental group, 9 articles focused on plantarflexion contracture, 5 on knee flexion contracture, and 1 on hip and knee flexion contracture. Ten studies focused on adults and 5 on children. Twelve used an exoskeleton or an orthosis to impose contractures, 1 used tapes and 2 imitated gait pattern of patients with contractures. In the descriptive group, 3 articles focused on plantarflexion contracture, 1 on stiff hip, 1 on hip flexion contracture and 1 on hip and knee flexion contracture. These 6 articles focused on children. In the surgery group, 7 articles focused on plantarflexion contracture (gastrocnemius, soleus or achille tendon lengthening) with 6 on children and 1 on adults. The extracted data from the included studies are reported in Table 2: study design or aim, number of subjects (gender and participants type), mean age in years, parameters evaluated, major joints assessed and/or device and main results.

### 3.2 Quality assessment

The Modified Quality Assessment Checklist with the evaluation for reporting quality, external validity, internal validity – bias, internal validity – confounding, and statistical power are described in Table 3. The ICC (+/- confidence interval) 0.87 (0.94/0.73) on the total score of the modified quality assessment showed excellent reliability (Shrout and Fleiss, 1979) and a p-value of 0.783 between raters; no significant difference was observed. In the 28 studies, the total mean score and standard deviation (SD) of the modified quality assessment was computed and was 12.8 (2.0) on 20 points. The mean score (SD) for reporting was 8.4 (1.3) on 10 points; for external validity, 1.3 (0.6) on 3 points; for internal validity (Bias), 2.0 (0.8) on 3 points; for internal validity (confounding), 1 (0.6) on 2 points, and for power, 0.1 (0.4) on 2 points.

## 4 Discussion

This systematic review aims to characterize the influence of contractures on gait kinematics. Twenty-eight articles were selected and evaluated by 2 reviewers with excellent inter-rater reliability. These articles were divided in three groups according to the study method of the contractures (experimental, descriptive and surgery studies). Even if the definition of contracture is not consistent in all the studies, they agree that a contracture induces a restricted passive range of motion of one or several joints. It also frequently returned that contractures appear as a result of pathologic conditions (such as burns, spinal cord injury, cerebral palsy, stroke, elderly age (Hoang et al., 2014), and impaired walking).

The primary reported contractures that have an effect on gait are ankle plantarflexion (gastrocnemius or soleus contracture), knee flexion (hamstrings contracture) and hip flexion (psoas contracture).

A **plantar flexion contracture** can be the result of gastrocnemius muscle retraction or soleus muscle retraction if it is not a neurological problem. Several authors have studied walking in plantarflexion without separating the effect of gastrocnemius and soleus contractures. These studies mainly showed a loss of heel strike at initial contact (loss of first ankle rocker), ankle plantarflexion (instead of dorsiflexion) occurring at midstance, and disruption of the third rocker in a terminal stance (Davids et al., 1999). **Compensations** showed a limitation in both hip and knee extension (stance phase) without a short hamstring or hip flexor (Goodman et al., 2004), but another study showed an increase in knee extension during midstance and specify that some subjects walk in knee flexion (Leung et al., 2014). Therefore, the different compensations occur at the knee level with a plantarflexion contracture: knee flexion or knee extension during mid-stance. An increase of pelvic tilt, an increase of knee varus, reduction of hip adduction, and more internal foot progression were also reported (Houx et al., 2013). The minimal plantarflexion contracture to significantly change kinematics and kinetics is 10° of plantarflexion (Houx et al., 2012).

**Knee flexion contracture** has an effect on excessive knee flexion during walking commonly observed in a crouch gait (Balzer et al., 2013). Compensations that have been observed include a decreased stride length and velocity, increased forefoot weight bearing and flexion posture in stance (Cerny et al., 1994). Matjacic and Olensek (2007) described knee flexion contracture by hamstring contracture. The minimal popliteal angle (hamstring contracture) to have an effect on gait was found to be 85° and included increased walking effort, decreased speed, decreased stride and step length and increased knee flexion in stance (Whitehead et al., 2007).

**Compensations** of a knee flexion contracture include increased maximal dorsiflexion, eversion and external rotation of the hindfoot (Balzer et al., 2013), decreased hip flexion in stance, increased posterior pelvic tilt, decreased pelvic obliquity and rotation and premature ankle dorsi and plantarflexion in stance (Whitehead et al., 2007). It seems that we need a minimum of 30° of knee flexion contracture to change trunk kinematics in all planes. In the coronal plane, the trunk is tilted to the contracture side in standing and walking. In the sagittal plane, anterior inclination of the trunk increased during walking. In the axial plane, trunk rotation to the unaffected side decreased during walking (Harato et al., 2008a, b). Knee flexion contracture by hamstring contracture, when it is associated with iliopsoas contracture, leads to a tendency to dorsiflex the ankle angle during midstance while the hamstring only shifted the hip angle toward extension (Matjacic and Olensek, 2007). When we analyze knee flexion during walking, we need to be careful not to systematically associate this flexion with a contracture because 80% of subjects with a crouch gait for example, had a hamstring with a normal length or longer despite persistent knee flexion during stance; it seems that this was a problem with hip flexion with a psoas contracture (Delp et al., 1996).

Regarding a **hip flexion contracture** (psoas contracture), Matjacic and Olensek (2007) described a hip flexion because of a psoas contracture linked with knee flexion during stance. An ankle dorsiflexion during midstance was observed in association with a hamstring contracture, as was described above. All subjects with a crouch gait had a psoas during walking that was shorter than normal by more than 1 standard deviation (Delp et al., 1996).

Numerous studies have examined a multilevel contracture because it is difficult to have subjects with only one contracture. Moreover, a contracture is often associated with other alterations, such as muscle weakness. The physiopathology of contractures and how they develop remains unknown.

## 5 Conclusions

Contractures influence walking depending on the location (muscle) and the contracture level (muscle-tendon length). Different types of research studied contractures in experimental, descriptive and surgery studies. After establishing a definition for contracture, this review identified several contracture alterations, such as plantarflexion, knee flexion and hip flexion contractures, with a kinematic description and presented possible different compensations. By continuing to study and to differentiate gait alterations from compensations, treatment can be better targeted (e.g., surgery and physiotherapy).

**Conflict of interest**

There are no conflicts of interest associated with this research.

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Table 1 : Inclusion and exclusion criteria

| | Inclusion | Exclusion |
|---|---|---|
| Population | Contractures or simulated contractures and healthy controls.<br>Pre-intervention (muscle lengthening) versus post-intervention | Acute contracture, sportsmen, animal<br>Splint as treatment, or splint with pathology |
| Intervention | Observation, evaluation, interpretation, Clinical Gait Analysis | Cast, splint, stretching, botulinum toxin, multi- surgery |
| Outcome | Kinematics, gait deviations, compensations | No kinematics |
| Type of study | Original research, published in peer-reviewed scientific journals, case-study research (observational) | Conference abstracts, non peer-reviewed publications, single case, systematic review. |

Table 2: Extracted data from the included studies

| First author | Study design or aim | Number of subjects / (gender M / F) / Participants type | Mean age in years (SD) or (range) | Parameters evaluated (other than spatiotemporal) | Major joints assessed and/or device | Main results (especially kinematics) |
|---|---|---|---|---|---|---|
| **Experimentation** | | | | | | |
| Balzer 2013 | Explore if an artificially induced bilateral knee flexion contracture (specially designed hip-knee-belt, to produce a symmetric artificial knee flexion contracture of 40°) causes compensatory mechanisms in foot motion during gait in healthy children. | 30 healthy children | 10.6 (+/- 1.8) | Kinematics Kinetics | knee flexion contracture | Increase in maximal dorsiflexion, eversion and external rotation of the hindfoot. |
| Cerny 1994 | Adaptation in the stance phase of gait to knee flexion contractures simulated by a knee-ankle-foot orthosis. | 20 healthy women | 25(+/- 3.6 ) | Kinematics Kinetics, EMG | Knee flexion contracture | Knee flexion contracture resulted in decreased stride length and velocity: Increase forefoot weight bearing and flexion posture in stance. |
| Davids 1999 | Evaluate primary from secondary compensatory with normal children, walking normally and voluntarily toe-walking in comparison to real toe walking gait pattern. | 32 normal children; 15 toe walker | 9.3 (5.4-13.6); 8.2 (5.4-13.6) | Kinematics Kinetics EMG | Imitation of plantarflexion (toe-walking) | Loss of heel strike at initial contact, disruption of the first ankle rocker, inversion of the second rocker, ankle plantarflexion (instead of dorsiflexion) occuring at midstance, disruption of the third rocker in terminal stance |
| Goodman 2004 | Determine what compensatory gait deviations may occur as a result of an imposed, unilateral equinus constraint. | 12 normal adult subjects | 23.7 (SD) | Kinematics Kinetics | Imposed ankle equinus by tape | Stance phase limitations in both hip and knee extension of persons with hemiplegia are not necessarily caused by limited length of the involved side hamstrings and/or hip flexors, but rather as the result of an ankle plantarflexor contracture alone. |

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|---|---|---|---|---|---|---|
| Harato 2008a | Investigate static and dynamic changes in trunk kinematics with simulated knee flexion contracture during walking. | 10 healthy females | 62 (60-64) | Kinematics Kinetics | Simulated knee flexion contracture | 30° contracture significantly changed the kinematics in each of the following planes. The trunk tilted to the contracture side in standing and walking. Posterior inclination of the pelvis in standing significantly increased. Anterior inclination of the trunk and pelvis significantly increased. Trunk rotation to the unaffected side significantly decreased. |
| Harato 2008b | Investigate the effect of knee flexion contracture on the knee mechanics both in affected and contralateral limbs during gait. | 10 healthy females | 62 (60-64) | Kinematics Kinetics | Simulated knee flexion contracture | knee flexion contracture greater than 15° led to mechanical overloads in both limbs. |
| Houx 2012 | Understand consequences of equinus foot on gait. Development of orthosis to induce equinus. | 10 healthy children | 9.7 (+/-1.25) | Kinematics Kinetics | Induced an adjustable degree of unilateral equinus | Significant kinematic and kinetic changes occurred at -10°, -20° and maximum plantarflexion. |
| Houx 2013 | Define threshold angle of equinus beyond which significant changes in 3D lower limb kinematics and kinetics occur in typically developing children | 10 healthy children | 9.7 (8-12) | Kinematics Kinetics | Induced an adjustable degree of unilateral equinus | Most of the kinematic and kinetic changes were significantly altered from the 10° condition: increased hip flexion at initial contact and increased anterior pelvic tilt, increased knee varus, reduced hip adduction and more internal foot progression. |
| Leung 2014 | Describe the effect of simulated plantarflexion contractures on knee biomechanics during the stance phase and on the spatiotemporal characteristics of gait by an ankle-foot-orthosis | 13 able-bodied adults | 30 (+/-7) | Kinematics Kinetics | Simulated ankle plantarflexion contractures | Ankle plantarflexion contractures are associated with an increase in knee extension during stance phase. Some people with simulated ankle contractures may walk with an increase in knee flexion instead. |

| | | | | | | |
|---|---|---|---|---|---|---|
| Matjacic 2006 | Characterize biomechanically three different toe-walking gait patterns, artificially induced, by a mechanical exoskeleton with elastic ropes, in six neurologically intact subjects and to compare them to selected cases of pathological toe-walking. | 6 neurologically intact subjects males | 22.5 (+/-1.9) | Kinematics Kinetics | Emulated contractures of soleus and gastrocnemius muscles | In ipsilateral side, soleus contracture mainly influenced the ankle angle trajectory, while gastrocnemius and soleus/gastrocnemius contractures influenced the ankle and knee angle trajectories. In the knee joint soleus contracture diminished, gastrocnemius contracture increased while soleus/gastrocnemius contracture approximately halved knee extensor moment during midstance as compared to normal walking. |
| Matjacic 2007 | To characterize biomechanically three different crouch walking patterns, artificially induced in eight neurologically intact subjects and to compare them to selected cases of pathological crouch walking. | 8 neurologically intact subjects males | 25.2 (+/-3.5) | Kinematics Kinetics | Emulated contractures of iliopsoas and hamstrings muscles by an exoskeleton with artificial muscles | Hamstring contracture (HAM) and iliopsoas/hamstring contracture (IPSHAM) shifted ankle-angle rotation profiles into dorsiflexion during midstance compared to iliopsoas contracture (IPS) and normal walking (NW) where ankle-angle trajectories were similar. HAM, IPS and IPSHAM shifted the knee angle of rotation profiles into flexion during stance, compared to NW. IPS and IPSHAM shifted hip angle of rotation profiles toward pronounced flexion while HAM shifted hip angle of rotation profiles toward extension, compared to NW. |
| Olensek 2005 | Evaluate and compare gait variability as recorded in normal gait and when being constrained by a mechanical exoskeleton with elastic ropes. | 6 neurologically intact subjects males | 22.5 (+/-1.9) | Kinematics Kinetics | Emulated contractures of soleus and gastrocnemius muscles | The most constrained SOL-GAS condition showed comparable gait variability. |

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| Ota 2014 | Investigate the acute influence of varied levels of restricted ankle dorsiflexion on knee joint sagittal and frontal plane kinematics and kinetics during gait using a dial lock joint and allowing unrestricted plantar flexion | 30 (15 / 15) healthy volunteers | 21.7 (+/-2.2) | Kinematics Kinetics | Restricted ankle dorsiflexion | Reduced ankle dorsiflexion during terminal stance of gait. Restriction in ankle dorsiflexion range of approximately 8°. |
| Romkes 2007 | Understand the differences between obligatory toe-walking as observed in hemiplegic CP gait and voluntary toe-walking. | 12 (8 / 4 ) hemiplegic children cerebral palsy(CP); 10 healthy adult (5 / 5) | 12.3 (+/-4.1); 29.5 (+/-3.3) | Kinematics Kinetics EMG | Healthy subjects mimicking toe-walking compared to hemiplegic CP. | The EMG pattern of the toe-walking leg was modified in gastrocnemius and tibialis anterior as compared with normal gait. This showed strong similarities to that of the patients and therefore can be regarded, at least in part, as activity required for toe-walking. |
| Whitehead 2006 | Determine the effect of simulated hamstring shortening on gait in normal subjects by an adjustable brace. | 6 normal female volunteers | 26.2 (21-42) | Kinematics Kinetics, Physiological cost index | Simulated hamstring shortening | Significant effects observed when the popliteal angle exceeded 85° and included increased effort of walking, decreased speed, stride and step length; decreased hip flexion and increased knee flexion in stance, increased posterior pelvic tilt, decreased pelvic obliquity and rotation and premature ankle dorsi- and plantar-flexion in stance. |
| **Descriptive** | | | | | | |
| Choi 2011 | Investigate the clinical relevance of hip kinematic and kinetic parameters, and 3D modelled psoas length in terms of discriminant validity, convergent validity, and responsiveness | 24 cerebral palsy children ; 28 normal children | 6.9 (+/-1.6) ; 7.6 (+/-2.4) | Kinematics Kinetics | Hip flexor (psoas) contracture | Maximum pelvic tilt, maximum psoas length, hip flexor index, and maximum hip extension in stance were found to be clinically relevant parameters in evaluating hip flexor contracture. |

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| Delp 1996 | Estimate the lengths of the hamstrings and psoas during normal and crouch gait on the basis of a computer model of the lower limb. Compare the lenghts of subjects'hamstrings and psoas muscle during walking with their lengths during static muscles tests. | 14 subjects with crouch gait ; 10 subjects without movement disorders | 10.5 ; 12.6 | Kinematics | Hamstrings and psoas lengths | 80% of the subjects with crouch gait had hamstring of normal length or longer, despite persistent knee flexion during stance. This occurred because the excessive knee flexion was typically accompanied by excessive hip flexion throughout the gait cycle. All subjects with crouch gait had a psoas shorter than normal during walking. |
| Gaudreault 2009 | Quantify the passive moments of force produced by ankle plantar flexor contractures and determine their mechanical contribution to the net ankle moment calculated during the gait of children with Duchenne muscular dystrophy (DMD). | 11 children with DMD; 14 healthy control children | 9.2 (+/-2.6) ; 9.7 (+/-1.9) | Kinematics Kinetics | Plantar flexion contractures | Contracture passive moments can compensate for the presence of progressive muscle weakness in the children with DMD. |
| Gordon 2013 | Describe the quantitative gait findings of the adolescent subject with a unilateral stiff hip and Determine whether these findings are similar to those of subjects presenting after arthrodesis. | 6 children with stiff hip | 13-17 | Kinematics Kinetics | Stiff hip | Increased arc of trunk and pelvic motion (sagittal, coronal); involved side: decreased arc of hip and knee motion (sagittal), decreased peak hip abduction in swing; contralateral side : increased arc of hip and knee motion (sagittal); and increased peak hip abduction in swing. |
| Svehlik 2010a | Detect outcome measures that could help differentiate between dynamic equinus and fixed equinus deformities. Describe the function of the gastrocnemius and soleus muscles when either dynamic triceps surae tightness or fixed equinus contracture was present. | 23 CP children ; 12 C | none | Kinematics | Dynamic triceps surae tightness and fixed equinus contracture | Characteristic pattern changes for the ankle joint kinematics and abnormal kinetic patterns were identified for both types of equinus. Muscle-tendon lengthening velocity is an interesting parameter to distinguish between fixed equinus and dynamic equinus gait in CP children. |

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| Svehlik 2010b | Confirm the hypothesis of the influence of the dynamic and fixed equinus deformity on the timing of knee recurvation (hyperextension). | 35 (21 /14) CP children<br>2 groups: early recurvatum (E-REC)<br>late recurvatum (L-REC)<br>12 developing healthy children | E-REC 8.01 (+/-2.7)<br>L-REC 7.62 (+/-2.36)<br>Healthy Children 10.32 (+/-2.96) | Kinematics<br>Kinetics<br>EMG | Dynamic and fixed equinus deformity on the timing of knee recurvation (hyperextension) | Both recurvatum groups had forefoot landing and neither achieved normal ankle dorsiflexion. Electromyographic examination revealed an abnormally high soleus activity in a single stance. Finding might simplify the decision as to which treatment to select for equinus deformity, present in patients with genu recurvatum. |
| **Surgery** | | | | | | |
| Baddar 2002 | Evaluate equinus gait relative to normal gait. Specifically, the length and excursion of the gastrocnemius-soleus muscle-tendon unit in relation to knee and ankle kinematics. | 34 (17 / 17) CP children<br>78 normal children | 7.2 (+/-3.4) ; 6.9 (+/-2.8) | Kinematics<br>Kinetics<br>EMG | Equinus gait and knee extension | Patients with an equinus gait pattern had a positive correlation (r = 0.7) between ankle and knee motion during single-limb stance. Ankle plantar flexion occurred while the knee moved into extension during single-limb stance. |
| Chimera 2012 | Compare the sagittal plane ankle and knee mechanics during the stance phase of gait in patients with non-spastic isolated gastrocnemius contracture (IGC) associated with overuse foot pathology to those of healthy controls. Determine if sagittal plane ankle and knee mechanics would be altered with gastrocnemius recession. Compare post-surgical ankle and knee sagittal plane mechanics in these patients to those of healthy control participants. | 6 (1 /5) adult patients clinically diagnosed with non-spastic IGC ; 33 (15 / 18) healthy control participants | 53.2 (+/-5) ; 48.9 (+/-8) | Kinematics<br>Kinetics | Isolated gastrocnemius contracture with full knee extension | Select post-surgical gait mechanics were unaltered; however, gait mechanics were not similar between non-spastic isolated gastrocnemius contracture patients and healthy control participants. Surgical intervention for patients with isolated gastrocnemius contracture does not appear to create any negative gait adaptations; however, patients may benefit from gait retraining post-recession as maladaptive gait patterns persist post operatively. |
| Galli 2005 | Analyze kinematic and kinetic effects of gastrocnemius fascia lengthening on gait pattern in CP children and the evaluation of push-off ability before and after treatment. | 20 CP children with equinus<br>10 healthy children | 8 (+/-2.7) ; 9 +/-3.1 | Kinematics<br>Kinetics | Gastrocnemius fascia lengthening and the effects at the knee joint | After gastrocnemius fascia lengthening, a significant increase in ankle dorsiflexion (reduction in equinus foot) at initial contact and an increased in knee extension at initial contact. |

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| Galli 2009 | Analyze kinematic and kinetic effects of gastrocnemius fascia lengthening over time using gait analysis in cerebral palsy (CP) | 12 CP children with equinus<br>20 healthy children | 9.3 (+/-2.7) ; 9 (+/-3.1) | Kinematics Kinetics | Gastrocnemius fascia lengthening and the effects at the knee joint | Improvements in ankle and knee kinematics and in ankle kinetics over time. The results showed that isolated gastrocnemius fascia lengthening improved lower extremity function without producing functional muscle weakness over time |
| Hemo 2006 | Determine whether children maintain adequate power generation at the ankle joint and how the kinematic parameters change after Achilles tendon lengthening for treatment of idiopathic toe walking (ITW) | 15 ITW children | 9 (4.2-13.1) | Kinematics Kinetics | Achilles tendon lengthening for treatment of idiopathic toe walking | Passive dorsiflexion improved from a mean plantarflexion contracture of 8 degrees to dorsiflexion of 12 degrees after surgery. Ankle kinematics normalized, with mean ankle dorsiflexion in stance improving from -8 to 12 degrees and maximum swing phase dorsiflexion improving from -20 to 2 degrees. |
| Lofterod 2008 | Assess the local and distant effects of isolated calf muscle lengthening in ambulant CP children. | 15 (8 /7) CP children | 8.8 (6-14) | Kinematics Kinetics | Equinus gait with isolated calf muscle lengthening | The improvement in ankle kinematics and kinetics supported the experience of other studies. The distant effects, which have previously not been evaluated in three planes, showed improvement in several kinematic parameters indicating that additional surgery in selected patients could be abandoned or delayed. |
| Tylkowski 2009 | Evaluated the outcomes of operative intervention for isolated equinus contractures in individuals with CP using instrumented gait analysis. | 27 CP children | 11.4 (+/-3.2) | Kinematics Kinetics | Gastrocnemius-soleus complex lengthenings on isolated equinus contracture | The passive range of motion at the ankle was improved and normalized postoperatively. Ankle kinematics normalized without compensatory changes occurring at the knee or hip kinematics. Ankle moments and powers become more normal but did not completely normalize. Kinematics and kinetics of the hip and knee were not adversely affected |

Table 3 : Modified Quality Assessment evaluated by MA and OC.

| Study ID | Reporting | | External validity | | Internal validity (Bias) | | Internal validity (Confounding) | | Power | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MA | OC | MA | OC | MA | OC | MA | OC | MA | OC | MA | OC |
| **Experimentation** | | | | | | | | | | | | |
| Balzer 2013 | 10 | 10 | 1 | 1 | 3 | 3 | 0 | 1 | 0 | 0 | 14 | 15 |
| Cerny 1994 | 9 | 8 | 1 | 1 | 2 | 2 | 1 | 2 | 0 | 0 | 13 | 13 |
| Davids 1999 | 9 | 8 | 2 | 1 | 3 | 3 | 1 | 2 | 0 | 0 | 15 | 14 |
| Goodman 2004 | 8 | 6 | 1 | 0 | 1 | 1 | 1 | 2 | 0 | 0 | 11 | 9 |
| Harato 2008a | 7 | 9 | 1 | 1 | 3 | 2 | 0 | 1 | 0 | 0 | 11 | 13 |
| Harato 2008b | 9 | 9 | 1 | 1 | 3 | 2 | 1 | 2 | 0 | 0 | 14 | 14 |
| Houx 2012 | 9 | 9 | 1 | 1 | 3 | 3 | 1 | 2 | 0 | 0 | 14 | 15 |
| Houx 2013 | 9 | 9 | 1 | 1 | 3 | 3 | 1 | 2 | 0 | 0 | 14 | 15 |
| Leung 2014 | 9 | 8 | 1 | 1 | 3 | 2 | 1 | 2 | 0 | 0 | 14 | 13 |
| Matjacic 2006 | 11 | 9 | 1 | 1 | 1 | 1 | 1 | 2 | 0 | 0 | 14 | 13 |
| Matjacic 2007 | 11 | 9 | 1 | 1 | 1 | 1 | 1 | 2 | 0 | 0 | 14 | 13 |
| Olensek 2005 | 10 | 9 | 1 | 1 | 1 | 1 | 1 | 2 | 0 | 0 | 13 | 13 |
| Ota 2014 | 9 | 9 | 1 | 2 | 3 | 2 | 1 | 2 | 0 | 0 | 14 | 15 |
| Romkes 2007 | 8 | 8 | 2 | 1 | 2 | 2 | 0 | 1 | 0 | 0 | 12 | 12 |
| Whitehead 2006 | 7 | 9 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 9 | 11 |
| **Description** | | | | | | | | | | | | |
| Choi 2011 | 9 | 9 | 2 | 2 | 2 | 3 | 0 | 1 | 2 | 2 | 15 | 17 |
| Delp 1996 | 7 | 7 | 2 | 2 | 1 | 2 | 1 | 2 | 0 | 0 | 11 | 13 |
| Gaudreault 2009 | 9 | 8 | 2 | 2 | 3 | 3 | 1 | 1 | 0 | 0 | 15 | 14 |
| Gordon 2013 | 5 | 4 | 2 | 3 | 1 | 0 | 0 | 1 | 0 | 0 | 8 | 8 |
| Svehlik 2010a | 9 | 8 | 2 | 1 | 2 | 1 | 0 | 2 | 0 | 0 | 13 | 12 |
| Svehlik 2010b | 9 | 9 | 2 | 1 | 2 | 2 | 1 | 1 | 0 | 0 | 14 | 13 |
| **Surgery** | | | | | | | | | | | | |
| Baddar 2002 | 9 | 6 | 2 | 2 | 2 | 2 | 0 | 1 | 0 | 0 | 13 | 11 |
| Chimera 2012 | 10 | 10 | 2 | 1 | 2 | 3 | 1 | 2 | 0 | 0 | 15 | 16 |
| Galli 2005 | 8 | 8 | 1 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 11 | 10 |
| Galli 2009 | 8 | 8 | 1 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 11 | 10 |
| Hemo 2006 | 8 | 6 | 2 | 2 | 2 | 1 | 1 | 2 | 0 | 0 | 13 | 11 |
| Lofterod 2008 | 8 | 7 | 2 | 1 | 2 | 1 | 0 | 1 | 0 | 0 | 12 | 10 |
| Tylkowski 2009 | 9 | 8 | 2 | 3 | 2 | 3 | 0 | 1 | 0 | 0 | 13 | 15 |