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ORIGINAL ARTICLE

Prevalence and classification of equinus foot in bilateral spastic cerebral palsy

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Abstract

Background Equinus is a common deformity in children with bilateral spastic cerebral palsy (BSCP). While dynamic equinus usually is treated by conservative therapy, fixed contractures need surgical correction. To choose the appropriate surgical method, it is important to discriminate between isolated gastrocnemius shortening and combined gastrosoleus complex contracture.

Methods In a retrospective study 938 patients with BSCP were studied. Patients underwent gait analysis and clinical examination. 248 patients (496 limbs) met the inclusion criteria. Data from motion analysis and clinical examination were used to calculate the prevalence and to further classify fixed equinus foot.

Results The prevalence of equinus was 83.3%. During clinical exam 246 (59.6%) limbs showed combined gastrosoleus complex contracture and 167 (40.4%) isolated gastrocnemius contracture. Max. DF at stance and mean DF at initial contact were significantly reduced in combined contracture, while max. ROM was increased ($P < 0.05$).

Conclusions Corroborating the results of previous studies, in this study there was a high prevalence of fixed equinus in patients with BSCP. The prevalence of equinus correlated with increasing age. As half of the patients with fixed equinus show a different involvement of gastrocnemius and soleus muscle, we recommend to apply Silfverskiöld's test to discriminate between those two types to choose the appropriate surgical therapy.

Keywords Cerebral palsy · Classification · Equinus foot · Equinus prevalence · Gait analysis

Introduction

Cerebral palsy is the most common cause for chronic motor disability in childhood [1]. In Europe it occurs in about two of 1000 live births, with about 70% of this population with the ability to walk [2]. In children with bilateral spastic cerebral palsy (BSCP) equinus is a common foot deformity and one of the most observed gait abnormalities [3]. Equinus deformity occurs due to spasticity and muscle imbalance with strong dominance of the gastrocnemius–soleus (gastrosoleus) complex. Both muscles are connected to the calcaneus through the Achilles tendon, although they both are involved in plantar flexion of the ankle, they do not have the same effects upon contraction. While the soleus muscle is spanning the ankle/subtalar complex alone, the gastrocnemius muscle is extending over the knee, which provides it with different biomechanical function [4]. Flexion of the knee can eliminate the effect of a tight gastrocnemius, while a tight soleus is not affected by knee bending [5].

Silfverskiöld's test is established for discrimination between isolated gastrocnemius contracture and combined shortening of the triceps surae muscle in equinus deformity [6]. Equinus is not initially present but develops during adolescence. Experimental data suggest that spastic muscles grow slower than muscles and bones in their normal siblings favoring contracture [4]. When equinus is present patients show a lack of ankle dorsiflexion and toe-walking pattern [7] resulting in ankle instability, increased risk of tripping, dysfunction, and secondary joint deformity [8, 9].

Dynamic contracture can be passively redressed to the neutral joint position, whereas fixed contracture cannot. Over the time dynamic tightness can develop into fixed

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contracture. While dynamic contractures can mostly be treated conservatively with orthosis, botulinum toxin injections and serial casting, fixed contracture requires surgical treatment such as lengthening of the triceps surae muscle or the Achilles tendon [10].

Fixed contracture requires operative treatment, but apart from lengthening of the Achilles tendon, there are several procedures aiming directly at the soleus or gastrocnemius muscle. Therefore, it is important for clinical decision making to differentiate between isolated gastrocnemius and combined gastrosoleus complex shortening.

The aim of this study was to investigate the prevalence of fixed equinus in our study population and to develop and evaluate a classification that discriminates between isolated gastrocnemius and gastrosoleus complex contracture using Silfverskiöld's test. In a further step we investigated if this discrimination had an impact on kinematics during gait.

Methods

Patients

A total of 938 patients with bilateral spastic cerebral palsy (GMFCS level I + II, mean age 18.2 ± 9.9 years) who were examined at our hospital by clinical examination and gait analysis between January 2007 and January 2017 were evaluated for inclusion criteria in a retrospective study. Inclusion criteria were (1) bilateral spastic cerebral palsy, (2) with the ability to ambulate without walking aid (GMFCS level I + II), (3) no previous musculoskeletal surgery or botulinum toxin injections within the last 6 months. Patients with severe mental disabilities were excluded. 248 patients (156 male, 92 female, 496 limbs) with a mean age of 16.0 ± 10.0 years satisfied the selection criteria. Patients were grouped subject to age: 3–8 years (39 male, 24 female, mean age 6.4 ± 1.4 years), 9–12 years (39 male, 16 female, mean age 10.3 ± 1.1 years), 13–16 years (25 male, 13 female, mean age 14.2 ± 1.0 years) and ≥ 17 years (53 male, 39 female, mean age 26.7 ± 8.3 years).

Prevalence and classification of equinus

During clinical examination the maximum passive dorsiflexion of the ankle at maximum knee extension was assessed. Equinus was defined as less than or equal to 5° of ankle dorsiflexion in knee extension. Limbs which showed equinus deformity were then categorized using Silfverskiöld's test. Isolated gastrocnemius contracture was defined as more than 5° of dorsiflexion at 90° knee flexion (Silfverskiöld 90°), combined contracture was defined as 5° or less of dorsiflexion at 90° knee flexion (Silfverskiöld 90°).

Clinical examination

Examinations were carried out by a physiotherapist and a study nurse with special education in pediatric neurodevelopmental therapy and gait analysis. The clinical examinations were always performed by the same investigators. A thorough clinical examination also involving Silfverskiöld's test were carried out. During the Silfverskiöld's test special attention was paid that the subtalar joint was inverted, locked and the talonavicular joint was stabilized to isolate the upper ankle joint.

Three-dimensional gait analysis

For gait analysis conventional three-dimensional motion capture using a Vicon® camera system (Oxford Metrics, Oxford, United Kingdom) was performed. Skin-mounted markers were applied to bony landmarks of the patient according to a standard protocol and kinematics were calculated according to a standard software procedure [11]. Patients were asked to walk barefoot along a 7 m walkway at a self-selected speed. At least five representative strides were averaged for further analysis and captured in our gait lab database.

Data analysis

The prevalence of equinus was assessed by clinical examination, afterwards classification into isolated and combined contracture was done as described above. Patients were grouped according to age. Two group comparisons between patients and controls were made using Student's t tests or χ^2 tests. Multiple means were compared among groups as indicators of discriminant validity by two-way ANOVA analysis with repeated measures, followed by pair wise post hoc tests. The total amount of limbs (496) was used for the calculation of the overall prevalence and the prevalence isolated and combined contracture for each age set. The height, weight, and body mass index (BMI) were recorded and compared between the different groups using ANOVA. Kinematics [mean dorsiflexion during stance phase/at initial contact/range of motion (ROM) (max–min dorsiflexion during stance phase)] of isolated and combined contracture were compared using Student's t tests. Statistical analyses were conducted using SPSS (IBM SPSS Statistics 25, IBM Ehningen, Germany) and GraphPad Prism (Prism 7.0 GraphPad Software, USA). The level of significance was set at $P < 0.05$.

Results

Prevalence of equinus foot and distribution of isolated gastrocnemius and combined gastrosoleus contracture

A total of 248 patients (496 limbs) out of the analyzed 938 patients of our database met the inclusion criteria. 413 of the 496 limbs had triceps surae shortening and showed equinus adding up to a prevalence of 83.3%. The prevalence of equinus foot seems to rise with increasing age and weight. While prevalence of equinus was 73.0% in the youngest group (3–8 years) it rose successively to 91.8% in the oldest group. Out of the 413 equinus deformities 246 (59.6%) were combined gastrosoleus contractures, whereas 167 (40.4%) showed isolated gastrocnemius contracture. As prevalence of equinus increased with age, distribution between isolated gastrocnemius contracture and combined gastrosoleus contracture remained constant (Table 1).

Kinematics

The kinematic data of isolated gastrocnemius and combined gastrosoleus complex contracture were compared as shown in Table 2. Patients with an isolated gastrocnemius contracture showed a significantly higher ($P < 0.0001$) dorsiflexion (DF) during stance phase and at initial contact ($P < 0.0001$) (Figs. 1 and 2) while maximum ROM (max–min dorsiflexion during stance phase) was significantly ($P < 0.0006$)

Table 1 The table shows the prevalence of equinus deformity in the different age groups measured by clinical examination (ankle dorsiflexion 5° or less in knee extension)

Variables	All	3–8 y	9–12 y	13–16 y	≥ 17 y	*P* value
Prevalence of equinus foot	413 (83.3%)	92 (73.0%)	88 (80.0%)	64 (84.2%)	169 (91.8%)	< 0.0001
Isolated gastrocnemius contracture	167 (40.4%)	35 (38.0%)	46 (52.3%)	22 (34.4%)	64 (37.9%)	> 0.05
Combined gastrosoleus contracture	246 (59.6%)	57 (62.0%)	42 (47.7%)	42 (65.6%)	105 (62.1%)	> 0.05
Height in cm						
Mean	148.5	118.0	139.8	160.9	168.9	< 0.0001
SD	± 23.1	± 9.7	± 10.6	± 8.4	± 11.5	
Weight in kg						
Mean	53.7	20.2	32.7	54.0	62.8	< 0.0001
SD	± 27.9	± 7.2	± 11.9	± 18.1	± 29.1	
BMI kg/m^2						
Mean	19.7	15.4	18.1	19.8	22.6	
SD	± 7.9	± 2.1	± 3.7	± 3.0	± 3.7	< 0.0001

Furthermore, age, body mass index (BMI), height, and weight are shown for different age sets. Each group is presented with mean and standard deviation (SD). *P* values were calculated using ANOVA

Table 2 The kinematic parameters (dorsiflexion (DF) at initial contact, maximum/minimum DF during stance phase) of patients with isolated gastrocnemius contracture (IC) and combined gastrosoleus contracture (CC) analyzed during stance phase and at initial contact in degrees (°)

Classification (IC/CC)	All		3–8 y		9–12 y		13–16 y		≥ 17 y	
	IC	CC	IC	CC	IC	CC	IC	CC	IC	CC
DF at initial contact in										
Mean	− 2.4	− 8.6	− 3.0	− 9.5	− 3.8	− 9.0	− 1.3	− 7.2	− 1.4	− 8.4
SD	± 6.5	± 9.1	± 6.4	± 9.7	± 7.7	± 9.5	± 4.3	± 7.9	± 6.1	± 9.0
Maximum DF in during stance phase										
Mean	13.3	8.4	10.6	5.0	13.8	9.8	12.6	9.8	14.7	9.0
SD	± 7.5	± 9.7	± 7.6	± 8.8	± 8.8	± 12.0	± 3.5	± 8.3	± 7.1	± 9.3
Minimum DF in during stance phase										
Mean	− 10.3	− 18.5	− 14.5	− 24.0	− 11.1	− 17.6	− 7.7	− 16.5	− 8.3	− 16.5
SD	± 9.9	± 12.7	± 14.5	± 14.0	± 8.0	± 11.5	± 5.0	± 10.5	± 8.4	± 12.3

Subgroups are shown for the different age sets. *SD* standard deviation

increased in patients with combined gastrosoleus complex contracture (Fig. 3).

Discussion

Prevalence

The aim of the study was to investigate the prevalence of fixed equinus on the basis of a large group of patients with BSCP. In a second step, a clinical classification should be introduced and evaluated by gait analysis. The results of the study clearly show that the prevalence in patients with BSCP is very high. It also increases continuously with increasing age, respectively, BMI. Of 496 limbs, 413 showed a fixed equinus deformity. In the youngest age group prevalence was 73.0% and increased to 91.8% in the over 16-year-olds. This corresponds to a total prevalence of 83.3%.

Previous studies have reported prevalence of equinus in BSCP between 58 and 70%, matching our results in the corresponding age sets [3, 4]. However, in contrast to the reports presented in the literature, this study included only patients with BSCP and a much wider age range.

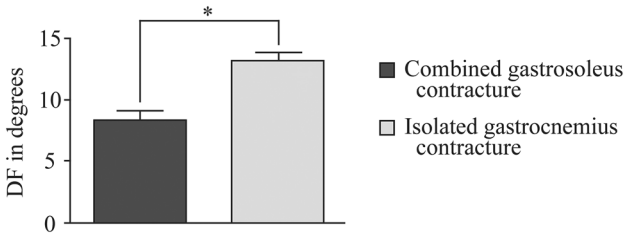

Fig. 1 Maximun dorsiflexion (DF) during stance phase in degrees (°) for isolated gastrocnemius and combined gastrosoleus complex contracture. Combined contracture displays a drastically reduced DF. $^{*}P$ value <0.0001. Data are expressed as the mean ± SEM

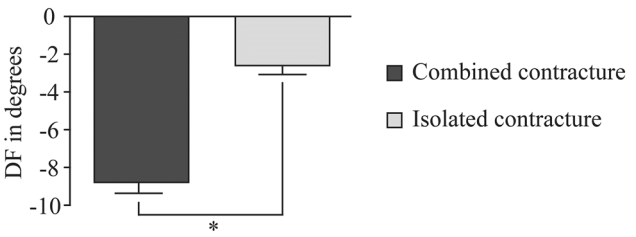

Fig. 2 Dorsiflexion (DF) at initial contact in degrees seen to present with a much more severe equinus deformity. $^{*}P$ value <0.0001. Data re expressed as the mean ± SEM

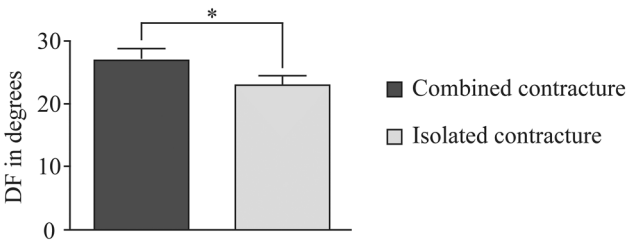

Fig. 3 Dorsiflexion ROM [max–min dorsiflexion (DF) during stance phase] in degrees for isolated gastrocnemius and combined gastrosoleus complex contracture. $^{*}P$ value <0.0006. Data are expressed as the mean ± SEM

Subclassification and severity

The subclassification into isolated gastrocnemius and combined gastrosoleus complex contracture by clinical examination showed significant functional differences during gait analysis. Patients with isolated contracture presented with a notably higher DF (13.3° ± 7.5 vs. 8.4° ± 9.7) during stance phase indicating a better function and higher DF (−2.4° ± 6.5 vs. −8.6° ± 9.1) at initial contact suggesting a less severe deformity. The maximum ROM was increased in combined contracture due to higher plantar flexion underlining a more excessive involvement of the soleus muscle. Interestingly, there was no significant difference in the distribution between isolated and combined contracture. In the literature there are no studies available, which correlate the involvement of gastrocnemius and soleus muscle with the kinematic data of motion analysis in patients with BSCP showing equinus.

According to the findings of this study, combined gastrosoleus contracture leads to a decreased ankle dorsiflexion during clinical exam and during gait. As a decreased ankle dorsiflexion with toe-walking pattern compromises mobility and independency, a combined contracture of the gastrosoleus muscle should be respected in surgical treatment.

Many surgical techniques have been described for the correction of an equinus deformity [12–16]. In general, surgical techniques aim at lengthening of the calf (Z-lengthening of the Achilles tendon, fascial lengthening, recession techniques). They can be divided in procedures that address the gastrocnemius alone or address the whole gastrosoleus complex. Subclassification of equinus deformity may be helpful in picking the appropriate procedure.

Limitations

This study investigated the prevalence of equinus deformity in a large study population with BSCP and suggests a subclassification into isolated gastrocnemius and combined gastrosoleus complex contracture. Limitations to this study are its retrospective design. Recent studies have described a poor inter- and intrarater reliability for the Silfverskiöld's test. However, to this point there is only one study which included only 24 healthy individuals [17]. In our study the clinical examinations were always carried out according to a standardized protocol by very experienced examiners.

In the literature there is no consensus in the question of how much knee flexion is needed to fully eliminate the restraining effect of the gastrocnemius muscle on ankle dorsiflexion. In some studies with non-weight-bearing measurements 90° of knee flexion was used [18, 19]. A recent biometric study reports that 20° of knee flexion fully eliminate the restraining effect of the gastrocnemius muscle [20]. These findings support our classification system. Furthermore, the clinical classification into isolated and combined contracture showed significant differences regarding function during gait analysis.

In summary, our data underline the importance of equinus deformity in patients with BSCP. The subclassification of fixed contractures into isolated and combined contracture which we suggest in this study could be useful for clinical decision making. The classification introduced by us needs to be validated in a prospective study.

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Author contributions AH and MK devised the idea for the research project. AH analyzed the data and wrote the manuscript with input from all authors. All authors provided critical feedback and helped shape the research, analysis, and manuscript. MK supervised the project. GB greatly contributed to the critical revision of the article. All authors read and approved the final version of the manuscript.

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Compliance with ethical standards

Ethical approval The study was approved by the responsible Ethics Committee of Heidelberg University Hospital.

Conflict of interest Each author certifies that he or she, or a member of his or her immediate family, has no funding or commercial associations (e.g., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted article.

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