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Original Study Article

Effects of a long-term triceps surae stretching program on the pennation angle of triceps surae heads in children with hypermobile flat foot and Achilles tendon shortening

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ABSTRACT

BACKGROUND: The retraction of the triceps surae, a pennate muscle, plays a key role in the pathogenesis of flatfoot in children. The pennation angle is defined as the angle between the triceps surae fascicles and aponeurosis.

AIM: This study aimed to evaluate the effect of a long-term triceps surae stretching program on the pennation angle of the triceps surae head in children with flatfoot and Achilles tendon shortening.

MATERIALS AND METHODS: The study included a total of 82 children with hypermobile flatfoot and Achilles tendon shortening. The pennation angle was measured by ultrasonography. Triceps surae stretching was recommended for 6 months as a basic exercise. IBM SPSS Statistics version 26.0 was used for the statistical analysis of data.

RESULTS: The study group included 63 children who engaged in stretching exercises, and the control group included 19 children who did not perform the stretching exercises at the required intensity. The study group showed a significant improvement in the foot posture index (FPI)-6, whereas the control group showed no change. The baseline foot dorsiflexion angles were 4.84° ± 0.10° and 4.81° ± 0.17° in the study and control groups. After 6 months in the stretching program, the dorsiflexion angles were 11.34° ± 0.24° and 4.85° ± 0.19° in the study and control groups, respectively ($p < 0.01$). The pennation angle of the triceps surae heads showed a significant increase in the medial head of the gastrocnemius and soleus.

CONCLUSIONS: The long-term stretching program in children with flatfoot led to a significant increase in foot dorsiflexion. This increase was associated with morphological and functional muscle restructuring, evidenced by a significant increase in the pennation angle of the medial head of the gastrocnemius and soleus. Further studies will identify the mechanisms underlying anatomical and functional muscle restructuring and their effects on anatomical foot parameters in flatfoot.

Keywords: flatfoot; triceps surae; stretching; pennation angle.

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Оригинальное исследование

Влияние программы длительного стретчинга трехглавой мышцы голени на угол пеннации ее головок у детей с гипермобильным плоскостопием и укорочением ахиллова сухожилия

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АННОТАЦИЯ

Обоснование. Ретракция трехглавой мышцы голени имеет большое значение в патогенезе плоскостопия у детей. Она относится к перистым мышцам, и наклон ее мышечных волокон по отношению к апоневрозу может быть измерен, а полученный угол обозначают как угол перистости или угол пеннации.

Цель — оценка влияния программы длительного стретчинга трехглавой мышцы голени на угол пеннации ее головок у детей с плоскостопием и укорочением ахиллова сухожилия.

Материалы и методы. Обследовано 82 ребенка с гипермобильным плоскостопием и укорочением ахиллова сухожилия. Угол пеннации измеряли при помощи ультразвуковой диагностики. В качестве основного упражнения рекомендовали стретчинг трехглавой мышцы голени длительностью 6 мес. Статистический анализ данных выполняли в программе SPSS v. 26.0.

Результаты. В основную группу вошли 63 ребенка, проводившие стретчинг, в контрольную — 19 детей, не использовавшие стретчинга с необходимой интенсивностью. В основной группе отмечено достоверное улучшение показателя шкалы оценки формы и положения стоп (FPI-6), тогда как в контрольной он не изменился. Исходный угол тыльной флексии стопы у детей основной группы составил 4,84 ± 0,10°, в контрольной — 4,81 ± 0,17°. Через 6 мес. стретчинга тыльная флексия в основной группе составила 11,34 ± 0,24°, в контрольной — 4,85 ± 0,19° (p < 0,01). Угол пеннации головок трехглавой мышцы голени достоверно увеличился в медиальной головке икроножной и камбаловидной мышц.

Заключение. Применение длительной программы стретчинга у детей с плоскостопием привело к достоверному увеличению угла тыльной флексии стопы. Эти изменения сопровождались морфологической и функциональной перестройкой мышцы, проявляющейся достоверным увеличением угла пеннации медиальной головки икроножной и камбаловидной мышц. Дальнейшие исследования будут способствовать выявлению механизмов, лежащих в основе анатомической и функциональной перестройки мышцы, а также их влиянию на анатомические параметры стопы при плоскостопии.

Ключевые слова: плоскостопие; трехглавая мышца голени; стретчинг; угол пеннации.

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BACKGROUND

Hypermobile flatfoot with Achilles tendon shortening (HFATS) represents a significant yet insufficiently studied condition in pediatric orthopedics. HFATS is characterized by reduced longitudinal arch height and restricted foot dorsiflexion, as determined through clinical tests. It was first identified as a distinct form of flatfoot by Harris and Beath in the 1940s [1]. Since then, its pathogenesis, diagnosis, and treatment have garnered attention because chronic manifestations can exacerbate pain syndrome and lead to secondary changes in the foot joints, such as progressive osteoarthritis.

Retractions of the triceps surae and/or Achilles tendon are considered critical in the pathogenesis of flatfoot in both children and adults. However, the causes and chronology of this phenomenon remain unclear. Nevertheless, a short Achilles tendon is recognized as a risk factor for the progression of pathological changes in flatfoot, and its assessment is an important diagnostic criterion for the condition. Many researchers consider interventions targeting the triceps surae and/or Achilles tendon integral to the surgical treatment of flatfoot. These include procedures on the tendon (various Achilles tendon lengthening methods) and surgeries on the gastrocnemius (recessions and aponeurotomies). However, the surgical treatment of flatfoot in children is not the first choice because of its relatively mild clinical manifestations compared with the degree of deformation. Most practical guidelines for conservative flatfoot treatment recommend stretching exercises for the triceps surae and Achilles tendon as a basic intervention; however, systematic studies, particularly those analyzing the efficacy of long-term stretching programs, are sparse.

In addition to its direct influence on foot shape and longitudinal arch height, stretching is believed to affect the morphological parameters of the stretched muscle. Thus, these parameters may uncover the mechanisms underlying the functional and anatomical remodeling of the muscle–tendon complex during stretching.

The triceps surae is a pennate muscle because its fibers are attached at an angle to the aponeurotic part rather than running parallel to the contraction axis. According to muscle contraction physiology, this anatomical organization allows more efficient force utilization [2]. The pennation angle (PA) is formed between the muscle fibers and aponeurosis [3]. It can be measured through anatomical studies of muscle specimens [4], magnetic resonance imaging [5], and, most commonly, ultrasonography [6]. In recent years, numerous studies have assessed the PA of the triceps surae and its heads under various physiological and pathological conditions [7, 8]. Many studies in sports medicine and physiology [9, 10] have described PA changes in response to different physical training regimens (strength exercises, stretching, different loading modes, etc.). However, divergent trends in PA changes were observed, likely due to differences in participants' age, baseline functional state (athletes vs. volunteers), and physical regimens applied.

Nonsurgical treatments for pediatric flatfoot primarily emphasize physical exercises. Among these, balance-improving exercises have shown positive effects [11]. Stretching is considered a potentially beneficial intervention for flatfoot; however, its efficacy has not been systematically demonstrated. In his foundational monograph [12], Vincent Mosca highlighted stretching as a primary conservative treatment and even suggested a simple device for this purpose; however, he did not provide systematic data on its efficacy.

We hypothesized that a long-term stretching program for children with HFATS promotes the adaptation of the muscle to new functional conditions, manifested as changes in the PA of the triceps surae heads.

This study is part of a broader investigation into the efficacy of a stretching program for children with HFATS. The morphological and functional tissue remodeling markers in these children may reveal the development of additional efficacy criteria and contribute to the understanding of the adaptive processes resulting from this intervention.

This study aimed to evaluate the effect of a long-term stretching program for the triceps surae on the PA of its heads in children with flatfoot and Achilles tendon shortening.

MATERIALS AND METHODS

The study included 82 children with HFATS. The diagnosis was based on clinical examination and calculation of the foot posture index (FPI-6), as recommended by the Russian consensus on the diagnosis and treatment of pediatric flatfoot [13]. The diagnostic criteria included a combination of flatfoot (FPI-6 score of ⩾8) and restricted dorsiflexion (<10°) determined using the Silfverskiold test with the hindfoot in a neutral position and metatarsal heads aligned perpendicular to the limb axis. The cohort comprised 57% girls and 43% boys, aged 7–17 (mean age, 11.4 ± 2.6) years. Children with neurological or other orthopedic conditions were excluded from the study.

Ultrasonography using a linear transducer (L14-3Ws) on a high-end Mindray Resona I9 device (Mindray Bio-Medical Electronics, China) was used to measure the PA. Measurements were performed with the child lying prone, ensuring relaxation of the gastrocnemius and soleus, with the foot hanging off the examination table. PA was measured separately for the medial and lateral heads of the gastrocnemius and soleus. The ultrasound transducer was positioned parallel to the tibial axis. Longitudinal scanning of each muscle head was performed, followed by transducer placement at the muscle midpoint. PA was determined from a single cross-section by measuring the angles for three nonadjacent muscle fibers, and the mean of these three measurements was calculated.

The primary intervention involved stretching exercises for the triceps surae. Parents and children received detailed instructions for the following procedure: The starting position required the child to stand with both feet on a rectangular wooden block (30–40 cm long, 20–30 cm wide, and 15–30 mm high), with the front and midfoot on the block and heels hanging freely. The children were instructed to keep their backs straight and their hands on a support surface. For stability, exercises were performed near a wall or table for balance. The participants slowly lowered their heels until they touched the supporting surface, stretching the triceps surae until discomfort or mild pain was felt. This position was held for 10–15 s, followed by a gradual return to the starting position. The exercises were repeated 15–20 times over a 15-min session. Parents were strongly encouraged to ensure regular and consistent adherence to the stretching regimen.

All patients diagnosed with HFATS during the initial visit were prescribed a long-term stretching program. They were invited for a follow-up examination 6 months later, with the inclusion criteria requiring follow-up between 6 and 9 months after the initial visit. During the follow-up, the patients were questioned about the regularity and duration of their stretching exercises.

For the intervention group, the inclusion criteria included the following compliance criteria: at least 4 days of stretching per week on average, no more than one missed week per month (e.g., due to vacations or exams), and a minimum session duration of 10 min. For the control group, the inclusion criteria included non-adherence to stretching recommendations or (at least one criterion) stretching for no more than 1–2 months, session durations <5 min, or fewer than three days of stretching per week. Most of the children in the control group did not adhere to the stretching recommendations. In contrast, the intervention group demonstrated high compliance with the therapy. Noncompliance was predominantly characterized by a complete absence of stretching exercises, with partial adherence observed only in rare instances. Parent-reported data were cross-referenced with the child's responses. For discrepancies, parent-provided information was prioritized for children aged 7–11 years, whereas responses from children aged 12–17 years were preferred.

Data collection and generation of the database were performed using Microsoft Excel 2019, and statistical analysis was conducted using IBM SPSS Statistics for Windows version 26.0 (IBM Corp., Armonk, NY, USA).

Quantitative data were initially tested for normal distribution using the Shapiro–Wilk test for samples <50 and the Kolmogorov–Smirnov test for samples ⩾50.

Descriptive statistics included mean ± standard deviation (M ± SD), medians, interquartile ranges of 25% and 75% Me [Q_1; Q_3], and minimum and maximum values. For the pairwise comparative analysis of independent samples, the parametric Welch *t*-test was used when the data followed a normal distribution, whereas the nonparametric Mann–Whitney *U* test was applied when one or both samples did not meet the criteria for normality. For the pairwise comparative analysis of the dependent samples (pre-/post-intervention), the parametric paired *t*-test was used when the data followed a normal distribution, whereas the nonparametric Wilcoxon test was applied when one or both samples did not meet the normality assumption.

Significance was set at $p < 0.05$. Differences with $p > 0.05$ were considered not significant.

RESULTS

Based on the compliance criteria described earlier, 63 children (mean age, 11.7 years) were included in the intervention group, whereas 19 children (mean age, 11.6 years) comprised the control group. Boys accounted for 54% of the intervention group and 64.7% in the control group, whereas girls represented 46.0% and 35.3%, respectively. These findings suggest that age and sex do not significantly influence compliance with the stretching regimen. The baseline FPI-6 scores were not significantly different between the two groups, allowing for valid comparisons. In the intervention group, a significant improvement in FPI-6 scores was observed following the stretching program, whereas no changes were noted in the control group.

Results for foot dorsiflexion and FPI-6 scores are summarized in Table 1.

As shown in Table 1, the baseline dorsiflexion angles in the intervention and control groups were 4.84° ± 0.10° and 4.81° ± 0.10°, respectively, with no significant difference ($p_1 = 0.773$). Six months or later after the initiation of the stretching program, the dorsiflexion angle in the intervention group increased to 11.34° ± 0.24° compared with 4.85° ± 0.19° in the control group ($p_2 < 0.01$). Similarly, no significant differences were observed in the control group before and after the intervention ($p = 0.850$), whereas changes in the intervention group were significant ($p < 0.01$).

The results of PA measurements for the right lower limb after 6 months in the intervention and control groups are presented in Tables 2 and 3, respectively.

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Table 1. Changes in the foot posture index (FPI-6) and dorsiflexion angle after 6 months in the intervention and control groups

Parameter		Intervention group		Control group		*p*
		Before	After	Before	After	
FPI-6	M ± SD	9.2 ± 0.8	7.8 ± 0.6	8.8 ± 0.6	8.8 ± 0.5	$p_1 = 0.104$ $p_2 < 0.001^{\#\#}$
	Me [Q_1; Q_3]	9 [9; 10]	8 [8; 8]	9 [8.5; 9]	9 [9; 9]	
	Min–Max	8–11	6–9	8–10	8–10	
p, intergroup differences, before and after the training		<0.001**		0.954		
Dorsiflexion angle	M ± SD	4.8 ± 0.8	11.3 ± 1.9	4.8 ± 0.7	4.8 ± 0.7	$p_1 = 0.773$ $p_2 < 0.001^{\#\#}$
	Me [Q_1; Q_3]	4.9 [3.9; 5.4]	11.6 [9.2; 12.6]	4.9 [4; 5.4]	5 [4; 5.3]	
	Min–Max	3.7–6.2	8.6–14.4	3.7–6.1	3.8–6.2	
p, intergroup differences, before and after the training		<0.001**		0.850		

Notes: ** Significant differences ($p < 0.05$) were identified using the Wilcoxon test for dependent samples. ## Significant differences ($p < 0.05$) were identified using the Mann–Whitney *U* test for independent samples. p_1, differences between the intervention and control groups before the intervention; p_2, differences between the intervention and control groups after the intervention.

Table 2. Changes in the pennation angle for the right lower limb after 6 months in the intervention and control groups

Muscle	Parameter	Pennation angle				*p*
		Intervention group		Control group		
		Before	After	Before	After	
Soleus	M ± SD	15.9 ± 4.2	18.6 ± 4.9	15.3 ± 3.4	14.3 ± 3.2	$p_1 = 0.543$ $p_2 < 0.001^{\#}$
	Me [Q_1; Q_3]	15.3 [12.2; 18.4]	17.9 [14.3; 31.5]	15 [13; 17]	15 [12; 16]	
	Min–Max	8–25.5	9.4–29.8	8–22	8–21	
p, intergroup differences, before and after the training		0.002*		0.385		
Lateral head of the gastrocnemius	M ± SD	14.7 ± 3.6	14.5 ± 3.5	14.4 ± 4.3	13.2 ± 4.1	$p_1 = 0.283$ $p_2 = 0.068$
	Me [Q_1; Q_3]	14.3 [12.1; 16.3]	14.3 [11.6; 16.3]	14 [11.5; 15]	12 [10; 14]	
	Min–Max	8–23.5	8–22	9–23	8–22	
p, intergroup differences, before and after the training		0.717		0.231		
Medial head of the gastrocnemius	M ± SD	22.5 ± 4.6	26.3 ± 5.4	23.7 ± 4.1	21.9 ± 3.6	$p_1 = 0.471$ $p_2 = 0.002^{\#\#}$
	Me [Q_1; Q_3]	23.4 [18.2; 25.2]	27.2 [21.3; 29.6]	24 [22.5; 26]	22 [21; 24]	
	Min–Max	13–31.6	15.3–36.7	13–31	12–27	
p, intergroup differences, before and after the training		<0.001**		0.071		

Notes: * Significant differences ($p < 0.05$) were identified using the paired *t*-test for dependent samples. ** Significant differences ($p < 0.05$) were identified using the Wilcoxon test for dependent samples. # Significant differences ($p < 0.05$) were identified using the Welch *t*-test for independent samples. ## Significant differences ($p < 0.05$) were identified using the Mann–Whitney *U* test for independent samples. p_1, differences between intervention and control groups before the intervention; p_2, differences between intervention and control groups after the intervention.

As shown in Tables 2 and 3, the PA of the medial head of the gastrocnemius and soleus showed significant increases, whereas no significant changes were observed in the lateral head of the gastrocnemius. The figure illustrates ultrasound images of the medial head of the gastrocnemius of a patient with HFATS before the stretching program and after 6 months into the program.

DISCUSSION

The causes of triceps surae retraction in flatfoot remain unknown, representing an area for further investigation. To understand the potential causes, anatomical and physiological changes in the triceps surae must be examined to elucidate the underlying mechanisms.

Table 3. Changes in the pennation angle for the left lower limb after 6 months in the intervention and control groups

Muscle		Pennation Angle				p
		Intervention group		Control group		
		before	after	before	after	
Soleus	M ± SD	13.6 ± 4.3	15.7 ± 4.7	13.4 ± 3.3	12.1 ± 2.7	p_1 = 0.873 p_2 = 0.008##
	Me [Q_1; Q_3]	12.2 [10.2; 16.1]	14.2 [11.8; 18.7]	14 [10.5; 16]	12 [10; 15]	
	Min–Max	7–26	8.1–29.6	8–20	8–16	
p, intergroup differences, before and after the training		0.015**		0.208		
Lateral head of the gastrocnemius	M ± SD	15.1 ± 3.7	15 ± 3.6	14.2 ± 3.8	13.1 ± 3.5	p_1 = 0.331 p_2 = 0.55
	Me [Q_1; Q_3]	15.3 [12.3; 18]	15.3 [12.2; 18]	15 [11.5; 16]	14 [11; 15]	
	Min–Max	8–22.9	8–22.4	8–22	8–20	
p, intergroup differences, before and after the training		0.842		0.379		
Medial head of the gastrocnemius	M ± SD	21 ± 4.1	24.3 ± 4.9	21.5 ± 4.8	19.5 ± 4.5	p_1 = 0.686 p_2 < 0.001#
	Me [Q_1; Q_3]	21.4 [18.4; 23.2]	24.8 [21.2; 26.9]	22 [19; 24]	20 [16; 22]	
	Min–Max	12–30.6	13.9–35.8	12–30	11–27	
p, intergroup differences, before and after the training		<0.001*		0.23		

Notes: * Significant differences ($p < 0.05$) were identified using the paired *t*-test for dependent samples. ** Significant differences ($p < 0.05$) were identified using the Wilcoxon test for dependent samples. # Significant differences ($p < 0.05$) were identified using the Welch *t*-test for independent samples. ## Significant differences ($p < 0.05$) were identified using the Mann–Whitney *U* test for independent samples. p_1, differences between the intervention and control groups before the intervention; p_2, differences between the intervention and control groups after the intervention.

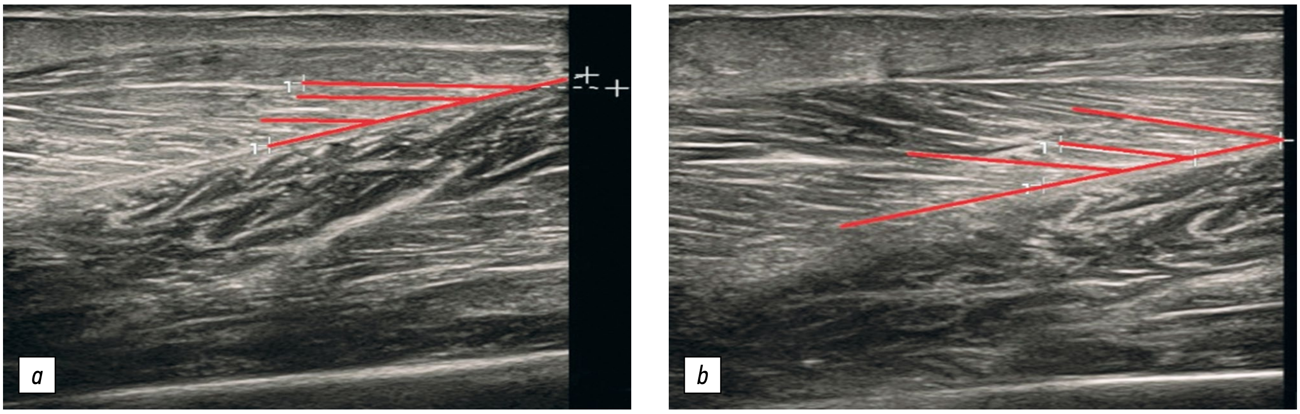

Fig. 1. Ultrasonography of the medial head of the gastrocnemius in a patient with hypermobile flatfoot and Achilles tendon shortening: *a*, before the stretching program; *b*, after 6 months of the stretching program

Among muscle examination methods, ultrasonography is widely used, offering real-time evaluation of anatomical parameters that characterize the muscle tissue condition. Obvious pathological changes in the muscles, such as tears, fibrosis, and atrophy, have relatively well-defined diagnostic criteria. However, such changes are rare in children with primary forms of flatfoot (unrelated to bone, nerve, or muscle system disorders) and cannot be considered a universal cause of reduced arch height. It is hypothesized that changes in the triceps surae associated with retraction are cumulative, developing gradually and beginning with minor deviations from normal parameters. The detection of these early changes in children with flatfoot could help identify the fundamental mechanisms underlying retraction in this condition. The PA is one of the frequently analyzed and discussed quantitative parameters of the triceps surae.

This study demonstrated that a long-term stretching program for the triceps surae significantly improved the dorsiflexion angle in children with HFATS. Ultrasonography revealed adaptive morphological changes in the heads of the gastrocnemius, including significant increases in the PA of the medial head of the gastrocnemius and soleus. No significant changes were observed in the control group, indicating that stretching influences PA parameters and presumably affects muscle function.

Because triceps surae retraction is a key factor in flatfoot pathogenesis, studying the adaptive mechanisms of the muscle alongside changes in foot morphology is crucial. This study investigated the effects of a long-term stretching program on the morphology of the triceps surae, focusing on its PA. A previous study showed that both acute and chronic stretching of the triceps surae can influence PA, with varying effects reported by different authors. The comparison of these changes with alterations in foot morphology will be a future research topic.

The pathogenesis of flatfoot is not solely attributed to triceps surae retraction and its sequelae. In children with flatfoot without retraction, secondary retraction may serve as an adaptive mechanism in response to reduced arch height and valgus positioning of the hindfoot. Although these hypotheses remain unproven, they provide a foundation for further scientific exploration. Future studies, including quantitative evaluations of muscle morphology, may offer deeper insights into this complex condition.

The effectiveness of the long-term stretching program has been confirmed in children with HFATS, and consistent adherence resulted in a significant increase in the dorsiflexion angle from 5° to 11°. Ultrasonographic findings indicated parallel morphological adaptations in the triceps surae, characterized by increased PA in its heads, objectively reflecting the adaptation of the muscle to new functional conditions.

Few studies have discussed the relationship between PA and triceps surae retraction in children, primarily focusing on patients with cerebral palsy. For instance, Wren et al. [14] reported slight differences in the PA between children with fixed and dynamic equinus deformities, with a significantly higher PA observed in children who underwent surgical correction of the equinus deformity.

The physiological significance of PA is widely debated. Currently, no consensus has been established regarding the direct influence of this parameter on the contractile capacity and other functional properties of the muscles. Many researchers associate increased PA with enhanced contractile strength and force generation efficiency, whereas others suggest the opposite based on experimental data. These discrepancies may arise from the relationship of the PA with the length–tension curve, a universal principle of muscle function wherein contractile strength increases with stretching up to a certain point before declining [15].

Thus, although PA may not serve as a universal indicator of muscle contractility, its changes reflect the physiological adaptation of the muscle to specific mechanical conditions. No previous studies have focused on PA changes in pediatric flatfoot. Nakamura et al. evaluated the effect of stretching in various durations on healthy adult volunteers, and they did not observe significant PA changes following a standard stretching protocol (three 60-s sessions at 30-s intervals, three days per week, for 4 weeks) [16]. Moreover, in a study of healthy adult volunteers, Mizuno reported an increase in the PA among individuals undergoing static stretching, in both isolation and combination with electrical stimulation, compared with the control group after an 8-week training program. However, the magnitude of this change was only marginally significant [17]. Panidi et al. [18] enrolled adolescent athletes (mean age, 13 years) who engaged in stretching exercises and observed a decrease in the PA of the lateral head of the gastrocnemius, with no changes in the medial head. Freitas and Mil-Homens examined the effects of an intensive 8-week stretching protocol on the architecture of the biceps femoris, demonstrating a reduction in PA following training [19].

Miskowiec assessed the immediate effects of stretching on healthy adult volunteers [2] and reported an increase in PA after the procedure. Similarly, Dennis [20] evaluated the acute effects of static stretching and found an increase in PA for both the medial and lateral heads of the gastrocnemius.

In the present study, PA was assessed separately for the right and left limbs. The overall trend—an increase in the PA of the medial head of the gastrocnemius and soleus, with no significant changes in the PA of the lateral head of the gastrocnemius—was consistent across both lower limbs. However, the specific values of these parameters varied between the limbs. A previous studies revealed fluctuations in PA between the right and left lower limbs [21], indicating that one limb is dominant. Although various methods can be employed to determine the dominant lower limb, these methods are not well established for children, compared with those for the upper limbs. Nevertheless, this study highlights asymmetry in both the baseline morphological parameters and their changes following a long-term stretching program. This observation warrants further investigation, given the common occurrence of asymmetry in flatfoot, which we aim to evaluate in future research.

The present findings also highlighted low compliance with the stretching program among patients. Neither age nor sex significantly influenced adherence, indicating that future research should explore factors such as parental education and the socioeconomic status of families. Notably, over half of the children in the intervention group engaged in regular sports activities, whereas nearly none in the control group did. This underscores the need for better understanding of the role of conservative treatments in children with varying physical activity levels.

Stretching exercises for the Achilles tendon are a standard recommendation for children with HFATS during outpatient visits or preventive checkups. However, the effectiveness of this intervention is often limited, with many patients not demonstrating any improvement, emphasizing the need for surgical interventions in certain cases. Our findings indicate increased dorsiflexion and morphological and functional adaptation of the triceps surae, characterized by PA changes, in patients who adhered to a long-term stretching program. In this regard, physicians should emphasize the importance of regularity, adequate duration, and the overall significance of this procedure when communicating with the parents and children, as this approach can markedly improve the effectiveness of treatment in children with HFATS.

CONCLUSION

This study demonstrated that a long-term stretching program for the triceps surae in children with HFATS resulted in a significant increase in the dorsiflexion angle. These changes were accompanied by morphological and functional remodeling of the muscle, reflected in an increased PA of both heads of the gastrocnemius and soleus. PA can be considered a criterion for monitoring the effectiveness of stretching, as these changes were not observed in the control group. Future studies are expected to elucidate the mechanisms underlying the anatomical and functional remodeling of the muscle and their effect on the anatomical foot parameters in flatfoot.

ADDITIONAL INFORMATION

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Competing interests. The authors declare that they have no competing interests.

Ethics approval. The study protocol for children was approved by the Local Ethics Committee of the H. Turner National Medical Research Center for Children's Orthopedics and Trauma Surgery, Ministry of Health of Russia (Meeting Protocol No. 24-4-2, dated November 19, 2024).

Consent for publication. Respondents provided consent for the processing and publication of the anonymized data.

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