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Which Is the Best Exercise for Abductor Hallucis Activation in Hallux Valgus? A Comparison Study for New Rehabilitation Perspectives

Giacomo Farì [1,*], Laura Dell'Anna [2,*], Francesco Paolo Bianchi [3], Rachele Mancini [2], Enrica Chiaia Noya [2], Carlo De Serio [2], Riccardo Marvulli [2], Luisa De Palma [2], Danilo Donati [4,5], Roberto Tedeschi [6], Maurizio Ranieri [2], Marisa Megna [2] and Andrea Bernetti [7]

1 Department of Experimental Medicine (Di.Me.S.), University of Salento, 73100 Lecce, Italy
2 Department of Translational Biomedicine and Neuroscience (DiBraiN), Aldo Moro University, G. Cesare Place 11, 70125 Bari, Italy; mancinirachelerosaria@gmail.com (R.M.); enrica.chiaianoya@gmail.com (E.C.N.); carlods210@gmail.com (C.D.S.); riccardo.marvulli@policlinico.ba.it (R.M.); depalmaluisa@gmail.com (L.D.P.); maurizio.ranieri@uniba.it (M.R.); marisa.megna@uniba.it (M.M.)
3 Department of Biomedical Science and Human Oncology, Aldo Moro University of Bari, 70121 Bari, Italy; frapabi@gmail.com
4 Physical Therapy and Rehabilitation Unit, Policlinico di Modena, 41125 Modena, Italy; danilo.donati@unimore.it
5 Clinical and Experimental Medicine PhD Program, University of Modena and Reggio Emilia, 41121 Modena, Italy
6 Department of Biomedical and Neuromotor Sciences (DIBINEM), Alma Mater Studiorum University of Bologna, Via Zamboni 33, 40126 Bologna, Italy; roberto.tedeschi2@unibo.it
7 Infradepartmental University Program of Physical and Rehabilitation Medicine, "V. Fazzi" Hospital, ASL Lecce, 73100 Lecce, Italy; andrea.bernetti@unisalento.it
* Correspondence: giacomo.fari@unisalento.it (G.F.); lauradellanna@gmail.com (L.D.); Tel.: +39-0832658416 (L.D.)

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Abstract: Background: Hallux valgus (HV) is one of the most common foot deformities and negatively impacts plantar support. The abductor hallucis (AH) is the most important muscle in the etiopathogenesis of hallux valgus, but the effectiveness of its rehabilitation clashes with the difficulty of identifying the most suitable exercises to activate it. Therefore, the aim of this study was to compare four different therapeutic exercises in the activation of AH in these patients. Methods: In this observational case–control study, 48 patients suffering from hallux valgus of moderate/severe grade, according to traditional radiographic classification and the Manchester scale, were divided into two groups: the case group underwent a monthly rehabilitation protocol for their foot deformity, whereas the control group was only evaluated without any intervention. The exercises were as follows: Toe Spread Out (TSO), Short Foot (SF), Forefoot Adduction (FA), and Flexion of the Metatarsophalanges (FM). Both groups were analyzed at baseline and 1 month later (at the end of rehabilitation for the case group) while performing the four mentioned exercises using a surface electromyograph (sEMG) to record the muscle activity of AH in terms of Root Mean Square (RMS) and Maximum Voluntary Contraction (MVC). Results: FA was the only exercise to determine a statistically significant improvement in AH at the end of the rehabilitation cycle, both in terms of RMS ($p = 0.015$) and in terms of MVC ($p < 0.0001$), whereas the other exercises did not produce any change in muscle activity in the comparison between times and groups or in the related interaction. Conclusions: FA seems to be the best exercise to activate and train AH, so rehabilitation programs for patients suffering from hallux valgus should consider this exercise as the starting point for improving plantar support, always considering the specific characteristics of HV. Further studies are needed to deepen the effectiveness of this exercise, with the aim of implementing rehabilitation strategies and rethinking traditional HV therapies, which are currently predominantly surgical.

Keywords: foot deformity; therapeutic exercise; rehabilitation; muscle

1. Introduction

Hallux valgus (HV) is one of the most common foot deformities. It is characterized by a structural alteration of the first toe ray, particularly a medial prominence resulting from the lateral deviation and pronation of the hallux, which represents the most visible feature of the complex three-dimensional deformity associated with HV. This condition causes aesthetic discomfort and negatively impacts plantar support and foot functionality, resulting in painful symptoms and limitations in daily activities [1,2]. The exact causes and progression of HV remain poorly understood. It affects approximately 23% of adults aged 18–65 years and 35% of those over 65 years [3]. This condition is complex and multifactorial, with various possible contributing factors that have not yet been fully elucidated. Specifically, HV shows a higher prevalence in females [4]. In fact, women tend to have higher rates of ligamentous laxity and different bony anatomy that may play a role in the deformity's development. In certain individuals, foot and toe muscular balance may be compromised due to a genetic predisposition to abnormal bone alignment and flexibility among the static stabilizers [5]. Additionally, wearing inappropriate footwear can exacerbate this condition, along with factors such as occupation, excessive walking, high body mass index (BMI), or weight-bearing activities, which are commonly significant factors favoring the worsening of HV. For these reasons, as well as for aesthetic considerations, there is an increasing tendency toward surgical intervention to correct hallux valgus [6].

The anatomical changes in HV involve a complex interplay between bones, soft tissues, muscles, and ligaments of the foot. The first metatarsal bone has a medial shift, whereas the proximal phalanx usually tilts laterally. This misalignment can result in increased stress on the surrounding structures, leading to inflammation, osteophyte formation, and capsular thickening around the metatarsophalangeal joint [7]. Moreover, the abnormal positioning of the great toe can cause altered weight distribution during walking, exacerbating symptoms such as pain in other joints, including the hip and knee joints, due to ankle imbalance, contributing to progression of the deformity [8].

Currently, there is no definitive solution for this condition apart from surgery, and the other available treatments do not seem to effectively reverse the deformity. Conservative management options for HV, such as orthotic devices, physical therapy, and lifestyle modifications, are widely used as first-line treatments due to their non-invasive nature. Orthotic devices help redistribute foot pressure and alleviate discomfort, whereas physical therapy focuses on strengthening foot muscles and improving biomechanics. Lifestyle changes, including weight management and appropriate footwear, can further enhance patients' quality of life. However, literature supporting the effectiveness of these conservative treatments is still limited, with a lack of high-quality clinical trials demonstrating long-term efficacy. Consequently, although these conservative options are beneficial, more rigorous research is needed to establish their role in achieving lasting relief and preventing the progression of HV [9]. When conservative approaches fail to reach satisfactory results, up to 30% of individuals with HV may require surgery, especially in cases of moderate-to-severe deformity. The most common complications following surgery for hallux valgus, such as first ray shortening, osteonecrosis, hallux varus, and recurrence, have been reported to occur in up to 50% of cases. Specifically, current data on recurrence rates are lacking, with the literature reporting variability, reaching 16% [10–12]. As a consequence, the need to improve the effectiveness of conservative treatments and the scientific evidence supporting them is an ever-present challenge, not only to avoid or delay surgery but also as a complementary tool to enhance the efficacy of surgery. In fact, postoperative physical therapy and gait training may lead to improved function and weight-bearing in patients who have undergone HV surgery [13].

In this sense, the abductor hallucis (AH) is considered a fundamental muscle to target in HV rehabilitation [14], which also focuses on proper activation of the intrinsic foot muscles globally and on balancing the activation ratio between AH and adductor hallucis. A variety of therapeutic exercises have been identified in the literature as beneficial for activating AH. Among the most commonly used exercises are Toe Spread Out (TSO), Short Foot (SF), Forefoot Adduction (FA), and Flexion of the Metatarsophalanges (FM) [15]. TSO is an essential exercise aimed at improving flexibility and strength of the intrinsic muscles of the foot, particularly those responsible for toe alignment. This movement encourages the active use of AH and helps to stop the toes from drifting toward the midline, which is a common problem in individuals suffering from HV. By practicing TSO regularly, the muscle strength and coordination necessary for proper toe positioning can be enhanced, potentially reducing discomfort and correcting alignment over time [16]. SF is a crucial exercise for foot rehabilitation, focusing on strengthening the intrinsic muscles that contribute to supporting the medial longitudinal arch. It has been shown that SF not only strengthens the foot muscles but could also enhance overall balance and control, which are beneficial for individuals suffering from HV [2]. FA is an exercise that involves a movement targeting the alignment of the forefoot. It emphasizes the engagement of the adductors and the intrinsic foot muscles, counteracting the lateral movement commonly observed in HV [17]. This exercise has been shown to be effective in enhancing foot stability, particularly during dynamic activities. The FM exercise focuses on increasing strength and flexibility in the muscles responsible for toe flexion. This exercise could be useful for counteracting the effects of HV, which makes the joint stiff and misaligned. By regularly practicing this movement, patients can improve joint mobility and muscle activation, contributing to foot function and stability [1]. However, it is not yet fully clear which therapeutic exercise is the most suitable and effective for stimulating AH. Clarifying this knowledge gap could be useful, as many approaches could consequently vary in terms of effectiveness, clinical applicability, and in relation to different degrees of deformity [18]. Therefore, this study aimed to compare four different therapeutic exercises with sEMG to assess their effectiveness in activating AH in patients suffering from HV, with the final goal of building new and more effective rehabilitation strategies.

2. Materials and Methods

In this case–control study, a total of 48 patients diagnosed with HV were recruited. Patients were selected at Bari University Hospital between January 2023 and December 2023. The included patients had HV classified as moderate/severe according to the Manchester scale [19].

The inclusion criteria were as follows: patients with HV classified as moderate or severe according to the Manchester scale of deformity; patients willing to participate in a comprehensive rehabilitation program, older than 18 years of age, and able to provide and sign informed consent. The exclusion criteria were as follows: patients suffering from any other orthopedic, rheumatological, or neurological disease involving the lower limbs; patients who had previously undergone foot surgery; and patients who had undergone any rehabilitation or local injection treatment in the previous 6 months.

The initial patient evaluations and diagnoses were performed by specialized medical doctors in a foot orthopedic and rehabilitation outpatient service. Radiographic images of the deformity were obtained and analyzed, ensuring that the radiographs had been performed within 6 months prior to medical evaluation.

The participants were randomly divided into two groups, namely the case group and the control group, using STATA MP15 software. These groups were homogeneous for age, gender (male vs. female), the pathological foot side, and the radiological and clinical grade of deformity. The case group underwent a one-month rehabilitation protocol specifically designed to address their foot deformity, whereas the control group received no intervention during the study period. The rehabilitation protocol included four key exercises aimed at enhancing the activation of the abductor hallucis (AH) muscle. The exercises were as follows:

- Toe Spread Out (TSO): The patients sit with their feet flat on the ground and spread their toes apart as widely as possible, maintaining this position for a set duration of time.
- Short Foot (SF): During this exercise, the patient sits with their feet on the floor and is asked to 'shorten' the foot by pulling the toes toward the heel without lifting either the toes or heel off the ground. This action engages the muscles of the arch, improving proprioception and stability.
- Forefoot Adduction (FA): To perform this exercise, the patient stands with their feet shoulder-width apart and consciously attempts to bring the toes together while keeping the heels aligned. FA helps to improve the coordination and control of foot movements, thereby promoting more neutral alignment of the metatarsophalangeal joints over time.
- Flexion of the Metatarsophalanges (FM): To perform this exercise, the patient is positioned in a seated posture and is instructed to flex the toes at the metatarsophalangeal joints, bringing them closer to the plantar surface of the foot. This movement is typically held for several seconds and can be repeated in sets.

The intervention comprised three sessions conducted each week, with each session lasting 40 min and led by a physical therapist with 10 years of experience in the field. Each session was structured as follows: 5 min of warm-up exercises for the lower limb muscles, followed by 5 sets of 10 repetitions for each exercise, with a 3-min rest period between sets. This resulted in a total of 5 repetitions per exercise per session. Each exercise was chosen for its potential to strengthen the intrinsic foot muscles, improve alignment, and alleviate the symptoms associated with HV. Both groups were assessed at baseline (T0), and again at the end of the rehabilitation period (T1), which lasted for one month and was performed only by the case group.

The evaluation was conducted by measuring AH activity during execution of the aforementioned exercises. AH was monitored using mDurance (mDurance Solutions SL-Granada, Spain), a surface electromyography (sEMG) system that provides real-time feedback. Specifically, a Shimmer EMG unit (Realtime Technologies Ltd., Dublin, Ireland) was used; it is equipped with a bipolar sensor engineered to register superficial muscle activity. Each sensor included two channels and functions at a sampling rate of 1024 Hertz, with a signal resolution of 24 bits. The pre-gelled electrodes had a diameter of 10 mm [20–22]. Data acquired from the Shimmer unit were transmitted to a mobile application, which then forwarded the information to a cloud service for simultaneous analysis. This system facilitated the generation of comprehensive reports based on the collected data. The electrodes were placed on the AH surface, providing valuable insights into muscle function by quantifying the electrical activity generated during muscle contractions. To position the sensors on the AH muscle, the skin was thoroughly cleaned to remove any oils or lotions, ensuring optimal adhesion of the sensors. The origin of the AH muscle was identified, located near the base of the first metatarsal on the medial side of the foot. sEMG sensors were then positioned directly over the AH muscle, specifically centered on the medial aspect of the foot, approximately midway along the first metatarsal, according to the visual instructions provided by the device itself. Following sensor placement, the participants were asked to perform muscle contractions to verify that the sensors were accurately detecting electrical activity.

In this study, the analysis focused on two primary metrics: Root Mean Square (RMS), a standard measure utilized to assess muscle activity during functional movements, which reflects the average electrical activity over time, and Maximum Voluntary Contraction (MVC), which indicates the maximum strength that a muscle can exert while performing a movement.

Ethical approval was granted by the Ethics Committee of Bari University Hospital (n.903/2023). All participants provided informed consent. All procedures were performed in accordance with the Helsinki Declaration principles of 1975, as revised in 2008.

Statistical Analysis

The sample size for this study was computed using the effect size that we expected to see (0.85). We considered $\alpha = 0.05$, a confidence interval of 95%, and power of 80%, obtaining a sample size per group of 22 patients. Finally, assuming a 10% dropout rate, 24 patients were considered for each group. The data analysis was conducted using Stata MP18 software. Continuous variables were expressed as mean $\pm$ standard deviation and range, whereas categorical variables were presented as proportions. The normality of continuous variables was assessed using skewness and kurtosis tests, and, where applicable, a normalization model was constructed for the variables that were not normally distributed. The continuous variables were compared between groups using either the independent samples t-test (parametric) or the Wilcoxon rank-sum test (non-parametric), and between times and groups using repeated measures ANOVA. The categorical variables were compared between groups using the Chi-square test. To assess the relationship between the difference between T1 and T0 for several outcomes and the determinants of group (B vs. A), age, gender (male vs. female), the pathological foot side, the radiological grade of deformity, and the number of days of adherence to the therapy, multivariate linear regression was employed. Correlation coefficients were calculated with a 95% confidence interval (95% CI). For all tests, a p-value < 0.05 was considered statistically significant.

3. Results

The study sample consisted of 48 subjects, 24 (50%) belonging to the case group and 24 (50%) belonging to the control group. The characteristics of the sample, by group, are described in Table 1.

Table 1. Sample characteristics.

Variable	Control Group (n = 24)	Case Group (n = 24)	Total (n = 48)	p-Value
Age (years); mean ± SD (range)	61.3 ± 6.5 (50–74)	60.4 ± 10.0 (28–77)	60.8 ± 8.4 (28–77)	0.859
Sex (Male) n (%)	11 (45.8)	6 (25.0)	17 (35.4)	0.131
Pathological foot side; n (%)				
• Left	13 (54.2)	14 (58.3)	27 (56.3)	0.771
• Right	11 (45.8)	10 (41.7)	21 (43.7)	
Radiological grade of deformity; n (%)				
• Moderate	11 (45.8)	11 (45.8)	22 (45.8)	1.000
• Severe	13 (54.2)	13 (54.2)	26 (54.2)	

The RMS values for the AH during the TSO, SF, and FM exercises did not show any statistically significant differences between the case and control groups. The only exercise that demonstrated a statistically significant improvement in performance, as indicated by the RMS values, was the FA exercise, as described in Table 2.

Table 2. Root Mean Square scores for the AH muscle in all the analyzed exercises, by group and detection times.

	T0	T1	Comparison Between Groups	Comparison Between T0 and T1	Interaction Between Time and Group
RMS TSO					
Control group	102.8 ± 37.2 (57.3–209.6)	106.7 ± 36.6 (68.6–195.4)	<0.001	0.337	0.695
Case group	59.4 ± 38.6 (11.9–133.5)	61.1 ± 38.3 (9.8–150.3)			
Total	81.1 ± 43.4 (11.9–209.6)	83.9 ± 43.6 (9.8–195.4)			
RMS SF					
Control group	86.1 ± 43.1 (37.1–220.6)	90.6 ± 38.8 (46.8–198.6)	0.189	0.124	0.960
Case group	69.4 ± 47.4 (16.2–188.3)	74.1 ± 47.2 (18.0–192.6)			
Total	77.8 ± 45.6 (16.2–220.6)	82.4 ± 43.6 (18.0–198.6)			
RMS FA					
Control group	66.2 ± 50.1 (12.2–154.3)	71.6 ± 50.1 (17.3–164.0)	0.929	<0.001	0.015
Case group	55.7 ± 54.4 (6.3–190.3)	79.5 ± 56.5 (21.1–236.2)			
Total	61.0 ± 52.0 (6.3–190.3)	75.6 ± 53.0 (17.3–236.2)			
RMS FM					
Control group	75.6 ± 54.6 (11.6–206.3)	81.1 ± 53.3 (9.2–206.3)	0.855	0.379	0.784
Case group	79.9 ± 55.3 (6.0–205.5)	82.7 ± 73.3 (16.2–270.0)			
Total	77.6 ± 54.4 (6.0–206.3)	82.0 ± 63.4 (9.2–270.0)			

AH: Abductor Hallux; RMS: Root Mean Square; TSO: Toe Spread Out; SF: Short Foot, FA: Forefoot Adduction; FM: Flexion of the Metatarsophalangeal Joints.

Similarly, the MCV values for the AH muscle during the TSO, SF, and FM exercises did not reveal any statistically significant differences between the case and control groups. Again, the only exercise that showed a statistically significant improvement in performance, as measured by the MCV results, was the FA exercise, as outlined in Table 3.

Table 3. Maximum Voluntary Contraction scores for the AH muscle in all the analyzed exercises, by group and detection times.

		MVC TSO			
Control Group	260.1 ± 110.3 (21.8–379.7)	273.4 ± 121.4 (105.3–543.6)	0.003	0.322	0.949
Case Group	165.4 ± 103.1 (21.8–379.7)	177.1 ± 118.3 (22.1–442.1)			
Total	212.8 ± 115.9 (21.8–489.2)	225.2 ± 128.2 (22.1–543.6)			
		MVC SF			
Control Group	200.0 ± 80.7 (33.4–313.3)	209.7 ± 140.2 (93.2–802.4)	0.152	0.270	0.894
Case Group	152.3 ± 80.7 (33.4–313.3)	164.7 ± 97.7 (37.6–458.7)			
Total	176.2 ± 110.9 (33.4–760.3)	187.2 ± 110.9 (33.4–760.3)			
		MVC FA			
Control Group	222.1 ± 112.4 (39.2–521.5)	216.2 ± 118.9 (32.5–521.5)	0.009	<0.0001	<0.0001
Case Group	216.6 ± 110.9 (34.6–521.3)	389.9 ± 118.8 (112.6–592.6)			
Total	219.2 ± 114.5 (32.5–521.5)	303.3 ± 143.5 (34.6–592.6)			
		MVC FM			
Control group	222.9 ± 214.9 (18.8–898.6)	219.9 ± 187.8 (24.4–706.4)	0.993	9244	0.328
Case group	238.9 ± 194.4 (16.6–1003.2)	204.8 ± 140.0 (52.7–649.4)			
Total	230.9 ± 202.9 (16.6–1003.2)	212.3 ± 164.1 (24.4–706.4)			

AH: Abductor Hallux; TSO: Toe Spread Out; SF: Short Foot, FA: Forefoot Adduction; FM: Flexion of the Metatarsophalangeal Joints; MCV: Maximum Voluntary Contraction.

4. Discussion

In response to the question in the title of this paper, our findings demonstrated that the RMS and MCV values for the AH muscle during the TSO, SF, and FM exercises did not show significant differences between T0 and T1 in the case group. On the contrary, the FA exercise was the only one to exhibit a statistically significant improvement in both RMS and MVC scores.

This finding suggests that FA effectively stimulates the intrinsic AH muscle, enhancing the coordination and control of foot movements. Assessment of the MVC values further emphasized the results observed in the RMS measurements. The patterns noted, with FA showing significant increases in muscle strength compared to the other exercises, align with literature highlighting the need for specific muscle training in pathological conditions of the foot [23]. Other studies have analyzed the significance of targeted exercises in enhancing outcomes for patients with foot diseases. A study conducted by Kilmartin et al. [24] demonstrated how intrinsic muscle strengthening exercises contributed to improving better alignment and overall function in patients with comparable foot deformities. Similarly, some studies on rehabilitation programs for other foot conditions, such as plantar fasciitis and flatfoot deformities, have shown that structured exercise routines aimed at strengthening intrinsic muscles can result in favorable functional outcomes [25,26]. These studies indicate a similarity in the effectiveness of rehabilitation across various foot pathologies, demonstrating the importance of rehabilitation in personalized multidisciplinary approaches [27]. In fact, HV management requires a multifaceted approach, and rehabilitation, particularly strengthening of the AH muscle, plays a critical role both pre- and post-surgery.

There is growing interest in the significance of targeted exercises to improve outcomes and prevent further progression of the deformity, improving foot function prior to surgical intervention. Recent literature explores the optimal exercises for strengthening the AH muscle, focusing on exercises such as TSO, SF, FM, and FA [28]. These exercises could play an important role in the rehabilitation of individuals suffering from HV, as enhancing the strength of the AH muscle can lead to better foot function, pain reduction, and the prevention of additional deformities. Jung et al. [29] highlight that specific exercises, such as toe curls and SF, effectively enhance muscle activation, suggesting that these could be beneficial pre-operatively. Strengthening the AH supports the medial longitudinal arch, potentially mitigating the severity of HV by maintaining proper foot alignment and reducing excessive pronation. Post-operative rehabilitation could be equally useful in restoring function and minimizing complications. Hwang et al. [14] provide evidence that targeted foot exercises lead to substantial improvements in muscle strength and foot stability, which are essential for successful surgical outcomes. By focusing on AH activation, rehabilitation can accelerate recovery and enhance post-surgical satisfaction by reinforcing foot mechanics and preventing recurrence.

In line with our results, Kim et al. [30] emphasize the efficacy of FA exercises, which specifically target the AH, contributing to improved dynamic balance and muscle coordination. Incorporating these exercises into rehabilitation protocols can further facilitate muscle conditioning and stabilization of the first metatarsal joint, which are key factors in managing HV deformities. Integrating targeted exercises focused on AH strengthening, both pre- and post-surgery, offers a comprehensive approach to HV management.

Additionally, Heo et al. provided valuable insights into the muscle activities associated with the examined exercises [31]. Their findings suggest that different exercises elicit varying degrees of AH activation, which is critical for clinicians when designing tailored rehabilitation programs aimed at maximizing muscle engagement. Moreover, Hwang et al. complemented these findings by employing pressure bio-feedback units to investigate AH muscle activity specifically in patients with HV [14]. This approach allows for a more comprehensive analysis of muscle function and engagement during rehabilitation exercises, enhancing the understanding of how targeted interventions can lead to improved clinical outcomes. The results on AH performance in TSO and SF can be explained by considering the instability of the first ray joint. The limitations in its ROM in patients with moderate-to-severe degrees of HV deformity hinder the execution of exercises such as SF and TSO. The compromised ability to move the first ray is influenced not only by muscle imbalances but also by mechanical joint restrictions [32–34].

The proposed rehabilitation program included exercises such as FA and FM, which are critical for restoring balance and coordination in individuals with HV. These exercises engage the entire musculature of the foot, bypassing the coordination and ROM necessary to correctly perform TSO and SF [35].

Our findings suggest that FA may be easier for patients with severe deformities, leading to improvements in AH activity, primarily because it requires minimal abduction mobility of the first ray, which is typically compromised due to bony issues. Since FA involves a lower degree of mobility and coordination, its incorporation into exercise programs was particularly effective in enhancing the performance and activation of the AH in patients with significant deformities. By integrating FA exercises into rehabilitation protocols, physical therapists can create targeted exercise regimens specifically aimed at addressing deficiencies in muscle function for patients with conditions such as hallux valgus and other forefoot deformities. As patients engage in forefoot adduction exercises, they learn to activate and control key muscle groups effectively, enhancing their overall foot biomechanics, ultimately leading to enhanced outcomes and quality of life [5,36].

An ideal rehabilitation program for hallux valgus should encompass various components to effectively address the multifaceted nature of the condition. A combined approach is essential, recognizing that hallux valgus not only affects toe alignment but also influences overall foot mechanics, stability, and patient quality of life. This program may include the use of orthotic devices, such as toe separators, HV splints, and protective barriers for the great toe [37,38]. Additionally, strengthening exercises targeting both the intrinsic and extrinsic muscles of the foot can enhance stability and functionality, thereby mitigating the progression of HV. Equally important are proprioceptive exercises, which should be integrated into the program to improve body awareness and balance. These exercises are essential for enhancing gait mechanics and reducing discomfort, particularly in individuals with compromised foot structures [39]. Furthermore, incorporating behavioral hygiene practices—such as educating patients on proper footwear choices and activity modifications—can foster long-term adherence to rehabilitation protocols and contribute to better outcomes [40].

In conclusion, incorporating FA into preventive strategies could significantly reduce the risk of developing hallux valgus in at-risk individuals. This exercise is particularly valuable in addressing muscle imbalances that often contribute to the onset of the condition. Furthermore, its application in post-operative rehabilitation programs can facilitate quicker and more effective recovery, enhancing overall functionality and quality of life for patients. By focusing on stabilizing the first metatarsal and aligning the great toe, FA not only promotes physical recovery but also supports psychological well-being, as patients experience reduced pain and improved mobility. Therefore, it is essential for healthcare professionals to integrate FA into their treatment plans to optimize both short-term rehabilitation effects and long-term health outcomes.

Despite the promising results associated with the FA exercise, this study acknowledges some limitations that warrant further exploration. The relatively small sample size limits the generalizability of the findings, as larger, more diverse populations may yield more comprehensive insights. Additionally, the short duration of the intervention raises questions about the sustainability of the observed benefits over time. Moreover, the subjects examined were primarily at a pre-surgical stage. Including patients at various stages of deformity, as well as those in the post-surgical phase, would provide a more nuanced understanding of how rehabilitation impacts different populations. Such an inclusive approach could elucidate the long-term benefits of FA across the continuum of care, enabling healthcare providers to develop more tailored and effective rehabilitation strategies. Future studies should aim to enroll a larger and more diverse sample, implement longer intervention periods, and potentially incorporate a wider variety of exercises to enhance muscle engagement and functional outcomes.

5. Conclusions

In this study, FA appears to be the most effective exercise for activating and strengthening the AH muscle. Therefore, rehabilitation programs designed for patients with HV should prioritize this exercise as a fundamental component for enhancing plantar support and improving overall foot biomechanics. It is essential to tailor these rehabilitation strategies to the specific characteristics of each case of HV, including the severity of the deformity and the individual's unique functional limitations. Incorporating FA into rehabilitation protocols could support muscle activation and address the underlying biomechanical issues associated with hallux valgus, thereby contributing to better alignment of the first ray and reducing lateral deviation of the great toe.

Further studies are needed to explore the long-term effectiveness of FA, as well as to assess various rehabilitation approaches in the treatment of hallux valgus. Future research should compare the efficacy of conservative treatments with traditional surgical interventions, emphasizing that conservative management techniques could provide more effective, non-invasive options that improve patient outcomes and reduce the reliance on surgery.

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