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Editor
Kezban YİĞİTER

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Türkiye Protez - Ortez Bilim Derneği

FROM EDITOR

Dear Readers,

We are pleased to bring you the latest issue of the Turkish Journal of Prosthetics and Orthotics Science, published by The Turkish Prosthetics-Orthotics Science Association. The interest and support we received following our first issue have reaffirmed that we are on the right path in this scientific journey.

Our journal continues to grow with the aim of sharing up-to-date, reliable, and high-quality scientific knowledge in the field of prosthetics and orthotics. In this final issue of the year, you will find original research exploring various aspects of our field, as well as a case report that provides insight into clinical applications. We believe that these articles will contribute both to academic knowledge and to guiding clinical practice.

Creating a platform where young researchers can share their work and where contributions from experienced scientists strengthen the community remains a key priority for us. As we close 2025, we wish to highlight once again the importance of advancing under the guidance of science and sharing knowledge. We hope the new year will be full of health, success, and scientific productivity for all.

We sincerely thank all the authors who contributed to this issue, our reviewers for their careful evaluations, the editorial board members, and everyone who supports our journal. At the Turkish Journal of Prosthetics and Orthotics Science, we aim to present even stronger content with each new issue.

We wish you an enjoyable read and a happy and successful new year.

Sincerely,
Prof. Dr. Kezban YİĞİTER
Editor

Türkiye Protez - Ortez Bilim Derneği

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TURKISH JOURNAL OF PROSTHETICS AND ORTHOTICS SCIENCE

ORIGINAL ARTICLES

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Research Article

THE EFFECTS OF CORE STABILISATION EXERCISES ON THE ATHLETIC PERFORMANCE IN AMPUTEE FOOTBALL PLAYERS

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Keywords

Amputee,
Core stabilization,
Football,
Performance.

ABSTRACT

Purpose: The aim of this study was to investigate whether a 6-week core stabilization training program induces measurable improvements in athletic performance parameters in amputee football players.
Methods: Twenty amputee football players aged 18-50 years were randomly allocated to a core stabilization group or a control group. Core stabilization exercise program (3 days/week over 6 weeks) was applied to the exercise group in addition to the routine training program, while control group followed the routine training program. Pre-and post training assessments included muscular endurans tests, sit and reach test and modified Thomas test, vertical jump test, functional reach test, and the 505 agility test.
Results: Core stabilization training yielded significant increases in trunk flexor and extensor endurance (dynamic push-up test repeats and static back extension time) within the exercise group ($p<0.05$). The 505 agility test and sit-and-reach test performance improved in both groups, whereas Thomas and Vertical Jump test performance did not change. The functional reach test was improved only in the control group ($p<0.05$).
Conclusion: Short-term core stabilization training enhances muscular but does not exceed the benefits of routie training for agility or jump performance in endurance amputee football players. Incorporation of core traninig into conditioning programs may support trunk endurance and functional capacity in this population.

INTRODUCTION

Balance and coordination are significantly affected in amputees following lower extremity amputations. Cutaneous inputs and proprioceptive information received from the plantar surface of the foot are of great importance for proper and balanced posture and ambulation. When a foot is disconnected from the ground, feedback and decreased proprioceptive sensation significantly reduce balance and coordination. Therefore people with lower extremity amputation have difficulty in movements such as standing, walking, running and jumping (1).

Amputee football is a form of football requiring sportive performance including endurance, strength, flexibility, speed and agility, which is played by the athletes by using

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forearm crutches (2). Amputation related loss of the extremity and muscle mass, changed sole-ground contact and impaired biomechanical configuration may affect sportive movements (2).

Body stabilization is required during sportive activities for creating maximal power in the distal segments and providing postural control (3). Maintenance of proper biomechanics is necessary for energy transfer from the body to the extremities (4, 5). It is crucial especially in order to decrease loads on the joints and maximise power generation in activities such as running, shooting and tackle (3). Core stabilization exercises are expected to improve sportive performance in movements including running, jumping, striking, turning and throwing (4). There are studies investigating the effect of stabilization exercise on balance, sprint and jumping performance in unhampered women and men football players (4, 6, 7). Although there are studies determining and comparing the factors affecting physical fitness and athletic performance in amputee football players (8-10), the effect of core stabilization exercise on the performance of amputee football players has not been studied. Therefore, the objective of this study was to investigate the effect of core stabilization exercise on athletic performance of amputee football players.

METHODS

Participants

A total of 20 amputee football players aged between 18-50 years who were playing in "Şahinbey Belediye Gençlik ve Spor Kulübü" (Sahinbey Municipality Youth & Sports Club) and "Şehitkamil Engelliler Spor Kulübü" (Sehitkamil Handicapped Sports Club). The athletes were randomly divided into two groups by coin toss as core stabilization exercise group (n=10; mean age: 30.00±10.81 years) and control group (n=10; mean age: 32.10 ±9.69 years).

Table 1. Information of Football Players About Amputation

		Exercise Group	**Control Group**
Amputation Side	Right	4	5
	Left	6	5
Amputation Level	Below The Knee	7	9
	Above The Knee	3	1

Football players with unilateral lower extremity amputation (Table 1) who had no injury in at least 6 months were included in the study. Athletes with significant visual and perceptual disorder, acute injury, those with mental and neurological problems, and the athletes who gave up playing football for any reason during the study period were excluded from the study. Before the beginning of the study, the players were informed in detail about the objectives and goals of the study and content of the training program. The study was approved by the Non-Invasive Research Ethics Committee of Hasan Kalyoncu University Faculty of Health Sciences by 11/10/2016 dated and 201612 number decision.

Assessments

Sociodemographic and physical characteristics (age, height, body weight, age of amputation and duration of using prosthesis) of the players were recorded at the beginning of the study. Physical fitness tests were performed within the season, at times where they took vacation and were not involved in strenuous activities. The measurements were made in the afternoon under the same environmental conditions and setting. Upper extremity muscular endurance was evaluated with push-up test, body endurance, dynamic, static and reverse sit-up test, flexibility, sit-and-reach test and modified Thomas test, jumping ability, vertical jump test, balance, functional reaching test, agility, and 505 tests. The evaluations were carried out in the beginning of the study and after 6 weeks.

Evaluation of Muscular Endurance

Dynamic sit-up test: Upper extremities of the football players were positioned according to the strength of the abdominal muscles by lying down in the supine hooked position with the knees bent. The player was asked to raise the head, neck, and shoulder towards the knees respectively, up to the scapular inferior angle. The number of movements that could be repeated and duration in seconds were recorded (10).

Push-up test: The players were asked to push-up face down with the elbows in flexion by bringing the elbows to the extension. The number of movements that could be repeated and duration in seconds were recorded (10).

Static reverse sit-up test: The players were positioned face down with the inguinal region on a stretcher and the hip smooth on the bed. They were then asked to raise anterior portion of the body with the hands along the smooth body. The duration during which this position could be maintained was recorded in seconds (10).

Static sit-up test: The player was given supine position with the knees bent as in the dynamic sit-up test. The player was then asked to raise the head, neck, and shoulder towards the knees respectively, up to the scapular inferior angle with the hands positioned according to the strength of the abdominal muscles. The duration during which this position could be maintained was recorded in seconds (10).

Evaluation of The Flexibility

The modified Thomas test: Hip joint of the player was positioned at a 28 cm distance from the bed and the extremity to be tested was left down the table. The other extremity was brought towards the chest by the examiner, and the distancing of the knee at the test side was recorded in centimeters (cm) (10).

Sit-and-reach test: The players were given a long sitting position with the knees in extension without shoes. They were then asked to reach the tapeline on a 25 cm width and 40 cm length wood piece. The knees were compressed to avoid flexion. The time during which the athletes could stay by extending their fingertips as far as they could was recorded. The test was repeated three times and the highest distance was used (cm) (17).

Evaluation of The Jumping Height

Vertical jumping test: The players were positioned as standing beside the wall. The maximal point at which players could reach by extending their arms near the wall was determined as the start point. They were then asked to jump without disrupting their body position. The distance between the start point and the point which the players could reach by jumping was recorded. The test was repeated three times and the highest value was used (9).

Evaluation of Balance

Functional reaching test: The football players were asked to stand beside the wall and to flex their arms near to the wall as the elbows being in the extension. The start point was determined from the tapeline on the wall. The players were then asked to go forward as far as they could without disrupting their balance, stepping and disconnecting the heel contact. The distance between the start point and the point which the players could reach by jumping was recorded. The test was repeated three times and the highest value was used.

Evaluation of Agility

505 Agility test: Photocell sensors (power Timer, New Test OY, Finland) were employed for this test (Figure 1). The photocell time was started as soon as the athlete started one meter behind the starting point and passed through this point, and was stopped after turning a 10 meters distance (on the right and left feet) and passing through the second photocell at 5 meters. The individual was given right for 3 trials and the lowest duration was recorded as the most

successful value (Figure 1). The evaluations were carried out on a grass ground with football boots (11).

Figure 1. 505 agility test

Training Program

Routine football training of the control and training groups included 15 minutes warming, 60 minutes technic-tactic work, and 10 minutes cooling period. Athletes in the training group received core stabilization exercise (10 minutes warming, 45-50 minutes core stabilization exercise training and 5 minutes cooling) 3 days a week for 6 weeks (Table 2) (Figure 2). The aim of the first week was to gain sensorimotor control by providing smoothness of the neutral spine. In the next weeks, the training was converted to dynamic and multiplane movements with maintained neutral spine position in order to raise awareness of motor control, endurance and kinesthetics. Core stabilization exercise training was planned as to be on a mat, sitting and standing positions with bilateral, unilateral and contralateral extremity movements (12).

Figure 2. Some mat exercise examples used during the training program

A follow-up chart was created to monitor attendance to the training. Exercise programs at the days when the athletes did not attend were completed before starting the new week program.

Statistical Analysis

Data obtained in this study were statistically analyzed using IBM SPSS Statistics v. 21.0 package software. Numerical variables were expressed as mean±standard deviation, and categorical variables as percentage. Normality of the data was studies using Kolmogorov Smirnow test. Since the data were non-normally distributed, comparisons between the groups were made with Mann-Whitney U test. Wilcoxon Rank test was used in the intragroup comparisons before and after the exercise program. $p<0.05$ values were considered statistically significant. Although non-parametric tests were applied due to the distributional characteristics of the data, effect sizes (Cohen's d) were additionally reported to quantify the magnitude and practical relevance of group differences. Reporting effect sizes provides complementary information to p-values and facilitates a more comprehensive interpretation of the results.

Table 2. Exercise Training Program By Weeks

Exercise Program	**1. WEEK (3*15 repeats)**	**2. WEEK (3*15 repeats)**
Right plank	Elbow at flexion	Elbow at extension
Left plank	Elbow at flexion	Elbow at extension
Forward plank	Elbow at flexion	Elbow at extension
Backward plank	Elbow at flexion	Elbow at extension
Sit-up	Hands crossed over the shoulders	Hands on the nape
Backbend	Hands on the ground	Without hand contact
Exercise Program	**3. WEEK (3*15 repeats)**	**4. WEEK (3*15 repeats)**
Anterior- posterior pelvic tilt	Sitting on a chair	Sitting on a Swiss ball
Shoulder rise up	Sitting on a chair	Sitting on a Swiss ball
Right trunk lateral flexion	Sitting on a chair	Sitting on a Swiss ball
Left trunk lateral flexion	Sitting on a chair	Sitting on a Swiss ball
Right choops	Sitting on a chair	Sitting on a Swiss ball
Left choops	Sitting on a chair	Sitting on a Swiss ball
Exercise Program	**5. WEEK (3*15 repeats)**	**6. WEEK (3*15 repeats)**
Reaching forwards	Unilateral forearm crutch	Bilateral forearm crutches
Lateral reaching	Unilateral forearm crutch	Bilateral forearm crutches
Single leg squat	Unilateral forearm crutch	Bilateral forearm crutches
Contralateral reaching	Unilateral forearm crutch	Bilateral forearm crutches

RESULTS

Demographic features were similar between the two groups ($p<0.05$) (Table 3). None of the individuals in the groups was excluded during 6 weeks. Three players in the exercise group and 8 in the control group were playing in the National Amputee Football Team.

Table 3. Comparison of the anthropometric and demographic features between the groups

	Exercise group	Control group	p
Age (years)	30,00 ± 10,81	32,10 ± 9,69	0,570
Height (cm)	176,20 ± 6,36	173,60 ± 7,17	0,323
Body weight (Kg)	70,30 ± 12,15	71,00 ± 10,99	0,910
Body mass index (Kg/m²)	22,68 ± 4,08	23,44 ± 2,25	0,545
Age of amputation (years)	12,30 ± 7,90	12,00 ± 8,46	1,000
Duration of using prosthesis (years)	11,90 ± 11,23	11,50 ± 7,63	0,939

Abbreventions; * $p<0.05$; cm, centimeters; Kg, kilogram; Kg/m², kilograms divided by square meters

When physical parameters of the groups were compared before the training program; number of dynamic sit-up test repeats and time of reverse sit-up were higher in the control group ($p<0.05$), while the other parameters were similar ($p>0.05$). On the other hand when the physical parameters of the groups were compared after the training program; only time of dynamic sit-up test were higher in the exercise group ($p<0.05$).

When the groups were compared in themselves before and after the training program; number of dynamic sit-up repeats, time of static reverse sit-up test, sit-reach test and 505 test values were significantly improved in the exercise group after the training program ($p<0.05$). Whereas sit-reach and 505 test results were significantly improved after the training program ($p<0.05$) (Table 4).

Table 4. Comparison of The Parameters in The Both Groups

	Exercise Group			Control Group			Between Group	
							Pre	Post
	Pre-training	**Post-training**	**p**	**Pre-training**	**Post-training**	**p**	**p**	**p**
Dynamic sit-up test (repeats)	27,70±8,12	36,30±13,46	**0,022***	40,40±12,43	44,80±11,18	0,201	**0,025***	0,088
Dynamic sit-up test (seconds)	52,50±17,32	72,20±17,83	0,066	51,70±9,78	54,40 ±8,04	0,444	0,649	**0,017***
Push-up test (repeats)	24,00±11,71	26,30±11,41	0,240	24,90±12,56	23,70±10,30	0,610	0,909	0,676
Push-up test (seconds)	36,80±14,77	40,70±12,76	0,169	32,30±7,97	29,60±10,91	0,440	0,383	0,069
Static sit-up test (seconds)	58,00±24,35	60,30±17,52	0,507	85,30±26,45	98,90±42,84	0,619	**0,038***	0,054
Static reverse sit-up test (seconds)	34,50±15,79	51,70±22,63	**0,044***	54,70±21,99	63,00±29,78	0,173	**0,037***	0,198
Modified Thomas test-right (cm)	5,00±1,31	5,10±0,91	0,564	6,05±1,32	6,40±1,82	0,304	0,087	0,087
Modified Thomas test-left (cm)	5,45±1,14	5,45±0,90	1,000	6,20±1,84	6,00±1,47	0,526	0,424	0,465
Sit and reach test (cm)	16,90±9,54	19,35±9,55	**0,007***	19,40±6,77	22, 25±7,85	**0,009***	0,449	0,325
Functional reaching test (cm)	29,45±6,18	32,50±5,43	0,092	28,95±7,34	31,90±6,43	**0,040***	0,791	0,650
Vertical jumping test (cm)	6,62±0,41	6,72±0,51	0,386	7,80±2,19	6,37±0,68	0,059	0,733	0,233
505 test (seconds)	18,80±3,20	19,95±3,15	**0,050***	19,05±3,01	21,00±2,00	**0,041***	0,290	0,364

Abbreventions; cm; centimeters, * p<0.05

When the groups were evaluated in themselves; among the physical fitness parameters flexibility and vertical jumping values were significantly increased in both groups after the training program (both p<0.05). However, no significant difference was found between the groups in terms of the difference following the training program (p>0.05). Whereas 505 agility test results did not change in both groups (p>0.05), the difference was in favour of the control group in terms of the intergroup difference values (p<0.05) (Table 5).

Table 5. Comparisons of the groups in terms of the differences in the parameters evaluated.

	Exercise group	Control group	p	d
Dynamic sit-up test (repeats)	8,60± 9,28	4,40±9,85	0,384	0,43
Dynamic sit-up test (seconds)	19,70±26,22	2,70±12,02	0,241	0,83
Push-up test (repeats)	2,30±7,92	-1,20 ± 6,20	0,225	0,49
Push-up test (seconds)	3,90± 7,85	-2,70±8,91	0,140	0,80
Static sit-up test (seconds)	2,30± 21,54	13,60±27,12	0,290	0,46
Static reverse sit-up test (seconds)	17,20±22,30	8,30±20,29	0,472	0,41
Modified Thomas test-right (cm)	0,10±0,57	0,35±0,88	0,473	0,33
Modified Thomas test-left (cm)	0,00 ±1,25	-0,20±1,14	0,788	0,16
Sit and reach test (cm)	2,45±1,85	2,85±1,94	0,333	0,21
Functional reaching test (cm)	2,75±4,19	2,95±4,08	0,648	0,04
Vertical jumping test (cm)	1,15±1,47	1,95±2,35	0,445	0,40
505 test (seconds)	0,09±0,43	1,43±2,02	**0,013***	0,91

Abbreventions; cm; centimeters, * $p<0.05$

DISCUSSION

In this study, in which we investigated the effect of core stabilization exercise on the performance of amputee football players, it was found that core stabilization exercises increased muscular endurance and positively affected functional capacity in a short time.

It was observed that age, height, weight, and BMI values were similar between the exercise and control group, and thus the groups were homogenous. Physical features that we obtained showed similarity with the results of some studies conducted on amputee football (9, 13, 14). In our study, we found that trunk flexors and back extensors were more enduring and stronger in amputee football players in the control group. This was attributed to that 80% of the players in the control group were playing in the National Amputee Football Team and tackling at the elite level.

Muscle strength, balance and trunk stabilization are important factors in amputee football as in other sports. In this regard, muscular strength and trunk stabilization are needed in the upper extremities. It was reported in a study that amputee football players performed 54 repeats of sit-ups in 75 seconds and 45 repeats of push-up in 38 seconds on average (10). In our study, core stabilization exercises increased the endurance of trunk and back muscles in the training group, but these exercises were observed to have statistically similar effects with the routine training program. Significant increases were shown in the strength and endurance parameters of trunk muscles following an exercise training for core region performed with a Swiss-ball (15, 16). At the same time, routine football training programs also showed similar effects. Cosio-Lima et al. reported that a 5-week standard strength program increased back strength in the experimental group (17). Durall et al. performed strengthening exercises on 30 women athletes for 10 weeks and found that the performance of trunk and back muscles was increased (18). In our study, similar effects between the groups might be resulted from that our duration was insufficient for neuromuscular adaptation that would be created by core stabilization. It is not clear in the literature how long it takes for the acute effects of core stabilization training to take place at a physiological level (19).

In our study, the core exercise program showed improvement in ability of vertical jumping as high as the routine program. Given that the lower extremity strength is a more important parameter for vertical jumping performance, although the endurance of the trunk muscles of the footballers in the training group improved, it may be considered normal not to affect the vertical jump performance. Tse et al. performed core exercises in rowers and while the endurance of trunk muscles improved, athletic performance parameters (shuttle run, horizontal and vertical jumping, 40 meters sprint) did not change after the training program. Although we prioritized dynamism and functionality for advancing the exercises in our study, not to utilize free weight to develop strength might affect our results. There are numerous studies in the literature supporting our findings. Previous studies reported that core stabilization training did not change the factors affecting sportive performance such as 40-m sprint, vertical jumping and shuttle run (20), reaction force perpendicular to the ground and on a horizontal plane (21), and throwing health ball (20). It has been reported that core stabilization exercises should be included in fitness programs for rehabilitation or prevention of injuries, and these exercises can not come to the fore in performance training (22).

In our study, sit and reach tests showed improvements in both groups, however the changes during 6 weeks were similar between the groups. We believe that routine football training affects the development of flexibility exercises, especially those performed during the warming. A 6-week preparation period has been reported to improve flexibility in amputee football (23). In a study by Ozkan et al. conducted to determine physical fitness features of amputee football players, the players were found to have a good flexibility (9). In addition, given that the level of amputation is a factor affecting flexibility, we think that this might differ in amputations at a higher level such as above the knee and further studies are needed on this issue.

Looking at our study in terms of balance, the control group showed improvement in functional reaching during the study, but the difference in change was similar between both groups. Although a positive correlation has been shown between flexor trunk muscle strength and dynamic core stability, no correlation could be found between core stability and balance (14). Our exercise program progressed to dynamic exercise from static mat exercises, yet the expected improvement in balance was not observed. In a review by Behm et al. investigating the effects of static and dynamic core stabilization training on athletic performance, it was stated that the athletes concentrated on free weight lifting and effects of static or dynamic core training were not clear (24).

In our study, we found no significant difference in both groups in terms of agility before and after the training program, while the improvement was better in the control group. We think that experience with forearm crutches in amputee football caused this difference. In addition, better agility in the control group can be explained by the larger number of players who were involved in the National Amputee Football Team. Speeding in amputee football has been stated to be associated with increased pelvic tilt and short duration of standing with forearm crutches (25). Larger number of players in the control group involved in the National Amputee Football Team may indicate that these players were specialized in the use of aiding devices at the elite level. However, it was thought that these results might also be associated with the level of amputation. Energy expenditure is known to be higher in above knee amputees compared to below knee amputees (26). In the present study, 30% of the amputee football players in the training group had above knee amputation, while this rate was 10% in the control group. This factor may be important in terms of a higher energy expenditure in the training group.

We believe that acute adaptation of core stabilization exercises did not occur especially in muscle fibers in the neuromuscular system in the development of power or strength related performance characteristics. Similarly, in a systematic screening by Reed et al. questioning core-performance relationship, majority of positive performance improvements were reported to be resulted from sportive-purpose training programs (27). It has been argued that the changes in power requiring performances such as strength, sprint and jumping should be integrated with free weight works and sports specific core exercises (28). From this aspect, the exercises that we chosen might be not specific or did not reach a sufficient level. The importance of upper extremity movements and biomechanical adaptations developed by athletes as a result of the changes in kinetic chain should not be ignored. Core stabilization training supporting neutral spine should be developed for the needs of amputee football players rather than standard training (27).

In our study which was designed as randomized controlled, despite the fact that we created homogenous groups, the majority of the players in the control group being involved in the National Amputee Football Team was seen as a limitation. However, we think that our study is important, because the parameters evaluated and the effects of core stabilization on the performance of amputee football players were studied for the first time.

Amputee football has different dynamics since it is played with a lower extremity and forearm crutches, and studies on the other sportive areas may not provide sufficient knowledge on amputee football. Therefore, we think that different methods should be developed for physical fitness of the players according to the needs of amputee football, and longer and different exercise approaches should be tested to improve their performance.

CONCLUSION

This study demostrated that a 6-week core stabilization training led to meaningful improvements in trunk muscular endurance in amputee football players but did not provide superior gains in agility, balance or jumping compared with routine football training. Core exercises may still be a useful component of training programs to support trunk endurance and functional capacity. Further studies with longer intervention time and population size are needed to clarify their impact on broader performance outcomes.

Ethics Committee Approval: The study was approved by the Non-Invasive Research Ethics Committee of Hasan Kalyoncu University Faculty of Health Sciences by 11/10/2016 dated and 201612 number decision.

Peer-review: Externally peer-reviewed.

Author Contributions: N.U.C: Data collections, conception and design, writing, K.Y: design, editing and final approval of manuscript, S.U: Critical review and writing, draft the manuscript. M.A.Ç: Critical review and writing.

Conflict of Interest: All authors declare that they have no conflict of interest.

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Research Article

AN INTEGRATED MECHANICS–HEMODYNAMICS MODEL ON THE EFFECTS OF PLANTAR MECHANICS AND CENTER OF PRESSURE DEVIATION ON VENOUS PUMP FUNCTION

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Keywords

Biomechanical modeling,
Center of pressure,
Gait biomechanics,
Plantar venous pump,
Venous hemodynamics.

ABSTRACT

Purpose: Lower-limb venous return requires the coordinated function of multiple peripheral pumps. Recent studies highlight the critical roles of plantar mechanics, foot morphology, kinematic chain alignment, and Center of Pressure (*CoP*) behavior in venous hemodynamics. This study proposes an integrated mechanics–hemodynamics model that unifies these parameters under a single analytical framework to quantitatively estimate venous flow (Q).

Methods: The model defines venous volume per step (V_{step}) as a function of arch height, plantar fascia/windlass mechanism, metatarsophalangeal (*MTP*) joint mobility, intrinsic muscle function, subtalar alignment, and mediolateral *CoP* deviation. *CoP* deviation during stance is normalized to a dimensionless parameter (D_{lat}), and its effect on venous volume is represented through a novel exponential coefficient, k_{CoP}, defined as $k_{CoP} = e^{-\beta D_{lat}}$. The influence of *CoP* deviation on calf–foot pumping mechanics is justified using Newton–Euler moment equations, Lagrangian energy landscape analysis, and Hamiltonian phase space behavior. The model is informed by quantitative evidence derived from pedobarography, gait analysis, Doppler ultrasonography, and plethysmography reported in the existing literature.

Results: Across four clinical scenarios derived from pedobarographic and hemodynamic literature (normal arch, pes planus, pes cavus, and calf pump insufficiency), the model reproduced venous flow patterns consistent with reported physiological trends and relative changes in Q.

Conclusion: This is the first analytical model to integrate plantar mechanics, kinematic chain alignment, *CoP* deviation, and venous hemodynamics into a unified quantitative structure. The framework offers a clinically applicable tool for assessment, orthotic design, and rehabilitation planning in patients with impaired venous return.

INTRODUCTION

Venous return in the lower limb depends not only on the heart's pumping capacity but also on the coordinated function of peripheral pumps, including the plantar venous pump, the calf muscle pump, the thigh pump, venous valves, and musculoskeletal alignment. Anatomical studies have demonstrated that the plantar venous pump is formed by deeply located venous structures situated between the intrinsic muscles of the foot, and that the classical notion of "Lejars' venous sole" largely reflects an artifact caused by high-pressure injection techniques (1,2). More recent imaging and dissection studies have established that these deep plantar veins

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empty with each step during weight transfer, indicating that the plantar pump constitutes an active component of early-phase venous return (2,3). Plethysmographic experiments have shown that manual activation or weight-bearing stimulation of the plantar pump produces a marked increase in upward flow through the posterior tibial vein (3). Previous biomechanical studies further linked heel-to-toe loading, arch deformation, and venous emptying patterns, highlighting that the plantar pump plays not merely an auxiliary but a first-stage role in venous return (4). These findings are supported by rehabilitation and vascular literature demonstrating the critical contribution of the plantar pump to early-phase venous propulsion (5).

Foot morphology exerts an equally significant influence on plantar pump performance and venous return. Studies examining dysmorphic arch structures, such as pes planus and pes cavus, show that static and dynamic alterations in arch geometry critically modulate plantar pressure distribution and the loading–unloading mechanics of the plantar venous compartment (6–8). In pes planus, medial arch collapse leads to broadened contact area, medially shifted pressure gradients, increased muscle strain, and altered timing of venous filling and emptying—findings associated with a higher predisposition to venous reflux (6,9). In contrast, pes cavus increases loading on the heel and forefoot due to reduced midfoot contact, thereby reducing plantar pump volume (7). However, its more stable and less zigzag mediolateral Center of Pressure (*CoP*) path in some individuals may reduce the proximal stabilizing demand on lower-limb musculature (10,11). Even among individuals without overt deformity, normal variations in arch height produce significant differences in plantar pressure patterns, footprint ratios, and muscle strain, demonstrating a direct link between arch morphology, load transfer, and muscular mechanics (10,12).

The calf muscle pump has long been considered the principal motor of venous return, and reductions in calf pump efficiency have been strongly associated with the prognosis and even mortality of chronic venous insufficiency (13–15). Doppler and plethysmographic studies indicate that calf pump output correlates with walking speed, muscle strength, and valve competence (13). Historically, the plantar venous pump was described through the concept of “Lejars’ venous sole,” a model later challenged by modern anatomical work (1,2). Contemporary dissection and imaging studies show that the plantar venous plexus acts as a functional reservoir that dynamically fills and empties during gait (2,3). Maximal emptying occurs during terminal stance and push-off, as demonstrated through dynamic ultrasonography and plethysmography (16). Although the calf pump is often described as the dominant venous pump, evidence shows that the plantar pump provides the initial impulse necessary to break the distal hydrostatic column (gravitational venous pressure below heart level), functioning as a first-stage driver (initial mechanical impulse initiating venous propulsion) in a mechanically serial pump system (3,17,18). When plantar pump function is restricted—such as during ankle immobilization—venous return decreases significantly despite maintained calf activity, confirming the interdependence of the two pumps (18). Yet most prior studies examined these pumps separately rather than within a unified mechanistic framework (19,20).

Plantar pressure patterns and Center of Pressure (*CoP*) trajectory reflect not only local foot loading but also proximal joint kinematics at the ankle, knee, and hip (21,22). Machine-learning models have demonstrated that lower-limb joint angles and even muscle activation patterns can be inferred with high accuracy solely from plantar pressure data (22,23). These findings support the interpretation of the foot as a "morphological sensor" encoding the overall kinematic chain (24). Consequently, deviations in *CoP*—particularly increased mediolateral excursions—generate heightened stability demands on muscles such as the peroneals, tibialis posterior, quadriceps, and hip abductors (25,26). This additional stabilizing moment represents a form of stability cost (additional muscular effort required to maintain mediolateral balance) that alters muscular workload and may diminish pump efficiency. Increased mediolateral *CoP* variability has been linked to fatigue, impaired balance, and an elevated risk of falls, even in healthy populations (26,27).

Classical venous hemodynamic models focus primarily on pressure–volume relationships, valve mechanics, hydrostatic gradients, and muscle compression, while largely neglecting plantar pressure patterns and *CoP* behavior (14). Observations such as "venous insufficiency is more common in pes planus" or "calf muscle strength increases ejection fraction" have remained phenomenological and unincorporated into a quantitative model (13). No existing framework integrates plantar mechanics, arch morphology, muscle–fascia interaction, joint mobility, arch deformation, mediolateral CoP deviation, and venous elasticity into a unified analytical structure (19,20). Orthotic and footwear interventions—including medial arch supports, lateral wedges, rocker-soled shoes, and custom insoles—have been shown to significantly modify plantar pressure distribution, *CoP* trajectory, and lower-limb kinematics (21,28). Some studies report improvements in venous symptoms and reductions in leg fatigue following such interventions, yet the mechanical mechanisms underlying these clinical benefits remain unmodeled (29). By linking plantar mechanics and *CoP* behavior to venous flow through dimensionless coefficients such as V_{step}, k_{CoP} and η_{foot}, an integrated mathematical structure may provide a rational basis for future orthotic design and personalized rehabilitation protocols (26).

Therefore, the aim of this study is to develop an integrated analytical model capable of quantitatively predicting venous flow. This model unifies plantar mechanics, muscle–fascia interaction, kinematic chain alignment, mediolateral CoP deviation, and venous valve and vessel properties within a single mathematical framework.

This approach posits that when foot morphology, kinematic-chain alignment, plantar fascia tension, joint mobility, and gait-stabilization variables are represented as dimensionless coefficients within a unified framework, the resulting mathematical structure can systematically quantify their collective influence on venous flow.

METHODS

The following section outlines the theoretical structure and mathematical formulation of the proposed mechanics–hemodynamics model, describing how each biomechanical component is incorporated into the venous flow framework.

Model Overview

This study proposes an integrated mechanical–hemodynamic model to quantify lower-limb venous outflow by incorporating plantar mechanics, fascia–muscle interaction, kinematic chain alignment, mediolateral Center of Pressure (*CoP*) deviation, and venous valve–vessel elasticity. The model components were structured mathematically such that each physiological mechanism acts as a multiplicative efficiency term within the venous stroke volume formulation.

Venous Flow Framework

Total venous outflow (Q) was defined analogously to the cardiac output relationship:

$$Q = Vstep \cdot f \cdot \eta_{total} \tag{1}$$

where:

- $\boldsymbol{Q}$: Total venous outflow (*mL/min*)
- $\boldsymbol{V_{step}}$: Venous ejection volume per step (*mL/step*)
- $\boldsymbol{f}$: Step frequency (*steps/min*)
- $\boldsymbol{\eta_{total}}$: Total system efficiency (dimensionless, 0–1), representing the proportion of mechanical energy effectively transmitted into venous propulsion.

Formally, this is analogous to the cardiac output relationship $CO=SV{\cdot}HR$; here, venous stroke volume replaces SV, and step frequency replaces HR.

Lateral *CoP* Deviation (D_{lat})

To standardize mediolateral *CoP* deviation across individuals:

$$D_{lat} = \frac{1}{T_{stance}} \cdot \frac{2}{W} \int_0^{T_{stance}} \left| x_{CoP}(t) - x_{ref}(t) \right| dt \quad (2)$$

where:

- $x_{CoP}(t)$: Instantaneous *CoP* position
- $x_{ref}(t)$: Reference *CoP* trajectory in healthy individuals
- W: Foot width
- T_{stance}: Denotes the duration of the stance phase of gait.

Normalization enables comparison across foot sizes and subjects.

Exponential Coefficient (k_{CoP})

The influence of *CoP* deviation on plantar and calf-pump efficiency was modeled using an exponential efficiency function.

$$k_{CoP} = e^{-\beta D_{lat}} \quad (3)$$

- When D_{lat}=0, k_{CoP}=1 (maximal efficiency)
- Increasing D_{lat} decreases k_{CoP} exponentially
- β: Subject- or population-specific sensitivity coefficient

Rationale for exponential form:

- Many biological systems (muscle efficiency, stability loss, energy expenditure) deteriorate exponentially beyond a deviation threshold.
- Mathematically smooth and differentiable, suitable for calibration.
- To our knowledge, this coefficient is introduced for the first time in this study.

The coefficient k_{CoP} is defined here and subsequently incorporated into the venous stroke volume formulation to explicitly capture the efficiency loss induced by mediolateral *CoP* deviation.

Venous Stroke Volume (V_{step})

Venous stroke volume per step (V_{step}) was modeled as a composite function integrating arch mechanics, fascia tension, windlass mechanism engagement, intrinsic muscle support, MTP joint mobility, and *CoP* deviation. The formulation captures how plantar compression and controlled deformation enhance venous filling, while dysfunctional loading patterns reduce it.

$$V_{step} = V_0 \cdot k_{arch} \cdot k_{fascia} \cdot k_{MTP} \cdot k_{muscle} \cdot k_{subtalar} \cdot k_{CoP} \quad (4)$$

where:

- V_0: Baseline venous filling under ideal loading
- η_{arch}: Arch compression–recoil efficiency
- ηf_{ascia}: Plantar fascia and windlass tensioning efficiency
- η_{MTP}: Contribution of *MTP* dorsiflexion to plantar venous filling
- η_{muscle}: Intrinsic and extrinsic foot muscle support
- η_{valve}: Venous valve–vessel elasticity contribution
- k_{CoP}: *CoP* deviation–dependent exponential coefficient (Eq. 3)

Rationale:

This multiplicative structure allows each biomechanical subsystem to independently scale venous ejection volume while preserving their physiological interactions. All k-coefficients are dimensionless (0–1) efficiency multipliers.

Stroke Volume Components Efficiencies

k_{arch} – Arch Height and Static Foot Anatomy

Arch height influences plantar fascia tension, pressure distribution, and the loading profile on the plantar venous reservoir. Flatfoot or excessively high arches disrupt plantar pressure distribution and increase muscular tension.

- Normal arch: $k_{arch} \approx 1$
- Dysmorphic arch: $k_{arch} < 1$

k_{fascia} – Windlass Mechanism

Dorsiflexion of the MTP joint increases plantar fascia tension; this windlass mechanism elevates the medial arch and enhances compression of the plantar venous pump. When the windlass mechanism is impaired, plantar venous ejection volume decreases markedly.

k_{MTP} – MTP Range of Motion

Reduction in MTP dorsiflexion ROM (e.g. hallux rigidus) impairs both the windlass mechanism and push-off mechanics, limiting adequate compression of the plantar venous plexus and reducing V_{step}.

k_{muscle} – Intrinsic and Extrinsic Muscle Function

Intrinsic plantar muscles and extrinsic plantar flexors contribute to active pumping of the plantar venous reservoir.

Weakness due to neuropathy or immobilization reduces pump efficiency.

$k_{subtalar}$ – Subtalar Alignment and Kinematic Congruence

Subtalar pronation/supination imbalance alters the line of load transfer and ground reaction force (*GRF*) vector alignment.

Excessive pronation or supination changes plantar contact area and moment arms, lowering pump efficiency.

k_{CoP} – *CoP* Deviation

k_{CoP} quantifies the effect of mediolateral *CoP* deviation from its ideal path on venous pump efficiency.

This coefficient is entirely novel and developed specifically in this study.

CoP Trajectory and Mediolateral Deviation

Figure 1 illustrates typical *CoP* progression and the mediolateral deviation component (k_{CoP}) used in the model.

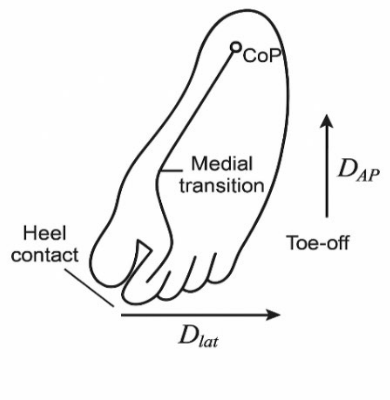

Figure 1. Center of Pressure (*CoP*) progression during stance, beginning at heel strike, transitioning across the lateral midfoot, and advancing medially toward toe-off. The mediolateral deviation component (D_{lat}) quantifies horizontal displacement relative to a normative reference path. Although anterior–posterior progression (D_{AP}) is shown for illustration, it is not used as a variable in the model. All variables shown are schematic representations intended to illustrate model structure rather than patient-specific measurements.

Total System Efficiency (η_{total})

Denotes the efficiency with which pressure waves produced by the venous pump propagate through the venous system:

$$\eta_{total} = \eta_{foot}\eta_{chain}\eta_{valve}\eta_{venous} \tag{5}$$

- η_{foot}: Local efficiency of plantar and calf pumps
- η_{chain}: Mechanical alignment of knee, hip, pelvis, and trunk
- η_{valve}: Venous valve competence
- η_{venous}: Vessel elasticity and lumen characteristics

Valve insufficiency and venous wall stiffness are associated with reduced pump efficiency in plethysmography and Doppler studies.

Newton–Euler Mechanical Interpretation

$$\tau_{GRF} = \boldsymbol{r} \times \boldsymbol{F}_{GRF} \tag{6}$$

where:

- $\boldsymbol{F}_{GRF}$: ground reaction force
- $\boldsymbol{r}$: vector from the joint center to the CoP location

As *CoP* shifts laterally:

- $|r|$ increases
- Inversion moment rises
- Peroneal muscles must generate a larger stability moment

Muscle moment budget:

$$\tau_{muscle} = \tau_{stability} + \tau_{pump} \tag{7}$$

Because total muscle moment is finite:

- Increased $\tau_{stability}$ reduces τ_{pump}
- Effective venous pressure wave decreases
- V_{step} decreases

The term "muscle moment budget" is used here to denote the finite total torque-generating capacity of the musculature, which must be distributed between postural stabilization and venous pumping functions.

The influence of *CoP* deviation on calf–foot pumping mechanics is justified using Newton–Euler moment equations (31), Lagrangian energy landscape analysis, and Hamiltonian phase space behavior.

Lagrangian Interpretation (Energy Landscape and Equilibrium Shift)

Using a linearized single-DOF frontal plane model:

$$I \cdot \ddot{q} + c \cdot \dot{q} + k_{eff}(D_{lat}) \cdot \left(q - q_{eq}(D_{lat})\right) = \tau_{muscle} \tag{8}$$

As *CoP* deviates laterally:

- k_{eff} increases (stiffer landscape)
- q_{eq} shifts
- Muscles must produce more stabilizing moment each stance phase
- Less mechanical energy remains available for venous pumping

Hamiltonian Phase Space (Increased Energetic Cost)

System Hamiltonian:

$$H(q, p; D_{lat}) = \frac{p^2}{2I} + \frac{1}{2} k_{eff}(D_{lat}) \left(q - q_{eq}(D_{lat})\right)^2 \tag{9}$$

With increasing *CoP* deviation:

- Potential energy increases
- Phase-space trajectories shift to higher-energy regions
- Stabilization cost rises
- Mechanical energy available for venous pumping decreases

This motivates reductions in both k_{CoP} and η_{chain}.

Final Integrated Equation

$$Q = \left[V_0 \cdot k_{arch} \cdot k_{fascia} \cdot k_{MTP} \cdot k_{muscle} \cdot k_{subtalar} \cdot k_{CoP}\right]. f. \left[\eta_{foot} \cdot \eta_{chain} \cdot \eta_{valve} \cdot \eta_{venous}\right] \tag{10}$$

The parameter *f* represents step frequency (steps per minute), linking gait cadence to venous outflow.

This equation unifies plantar mechanics, kinematic chain alignment, venous valve and vessel properties, and *CoP* deviation into a single analytic structure that predicts venous outflow (Table 1).

Table 1. Model Components and Their Contributions

Mechanical Framework	**Mechanical Component Explained**	**Contribution to the Model**
Newton–Euler Analysis	Describes how mediolateral deviation of the Center of Pressure alters the external inversion–eversion moment arm, increasing the stabilizing moment demand on the ankle–subtalar complex.	The additional stabilizing moment demand reduces the muscular moment available for venous pumping, leading to a reduction in the venous pumping efficiency represented by a lower contribution of the *CoP*-related efficiency term.
Lagrangian Analysis	Demonstrates how *CoP* deviation modifies the effective stiffness of the ankle–subtalar system and shifts the equilibrium position of the joint during stance.	Increased stiffness and a displaced equilibrium position require greater stabilizing effort from the musculature. This reduces the mechanical energy that can be allocated to venous pumping within the model structure.
Hamiltonian Phase-Space Analysis	Shows how *CoP* deviation increases the energetic cost of maintaining dynamic stability during the stance phase of gait.	The rise in energetic cost decreases the mechanical energy budget available for venous return. In the model, this is mathematically expressed as reduced pumping efficiency through decreases in *CoP* efficiency and kinematic-chain efficiency terms.

Model Validation Strategy

A structured, literature-based validation strategy was implemented to evaluate whether the proposed model reproduces the relative and directional patterns in venous flow documented in clinical and biomechanical research. This framework ensured that the model behaved in a physiologically coherent manner and captured the mechanical–hemodynamic relationships consistently reported across the literature.

The validation approach consisted of the following core components:

- Identification of characteristic mechanical features associated with normal arch morphology, pes planus, pes cavus, and reduced calf pump function, based on pedobarography, plethysmography, Doppler ultrasound, and gait studies (2,5,7,9–10,15,18–22,25–26,28–30). These features provided the empirical foundation upon which each clinical scenario could be mechanistically represented.
- Mapping these empirical descriptors to corresponding model parameters, including

– η_{arch}, η_{fascia}, η_{MTP}, η_{muscle}

– η_{foot}, η_{chain}, η_{valve}, η_{venous}

– the mediolateral deviation term D_{lat} and its exponential effect k_{CoP}

– and the composite venous stroke volume V_{step}.

This mapping allowed each clinically documented mechanical alteration to be explicitly translated into a model parameter shift.

- Comparing model-generated outputs after normalization of all values to the venous flow predicted under healthy-arch reference parameters. This enabled evaluation of relative differences across conditions and allowed the assessment of whether the model captured the correct *directionality* and *magnitude proportions* without requiring subject-level prospective data.

This structured approach ensured that the model's predictions were grounded in empirical biomechanics and venous hemodynamics, while remaining robust to inter-study variability.

This approach allowed the evaluation of whether the model behaves in a physiologically consistent manner without requiring subject-level prospective data.

Reference Data Used for Model Parameterization

Validation relied on four domains of prior research:

- Venous emptying metrics

Plethysmographic and Doppler studies provided reference ranges for venous ejection volume, ejection fraction, and venous refilling time (7,18,19,21,26). These informed the calibration of V_0, η_{foot} and η_{valve}.

- Plantar pressure and *CoP* characteristics

Pedobarographic studies reported typical values for footprint area, peak pressures, and mediolateral *CoP* variability in both normal and pathological foot morphologies (2,5,22,29,30). These informed k_{arkch}, k_{fascia}, D_{lat}, k_{CoP}.

- Kinematic-chain efficiency

Gait and IMU-based studies estimating joint angles from plantar pressure were used to constrain η_{chain} (15,25).

- Plantar deformation mechanics

Windlass mechanism efficiency, arch deformation behavior, and MTP joint stiffness from prior work informed k_{MTP} and V_{step} (4,13,28).

Model Parameterization Procedure Based on the Literature

Model parameters were tuned within physiologically reported ranges derived from the literature, and no subject-level experimental calibration was performed.

Stage 1: Baseline Fit (Normal Arch)

Parameters were tuned so that the predicted venous flow for individuals with normal arch morphology fell within previously reported physiological venous flow ranges. The goal was to ensure correct magnitude and biomechanical plausibility.

Stage 2: Scenario Parameterization

Each clinical condition was represented using literature-derived mechanical characteristics:

Pes Planus

Characteristics documented in literature:

- lower medial arch height
- broader footprint area
- altered plantar pressure distribution
- greater mediolateral *CoP* variability
- reduced windlass efficiency

These characteristics corresponded to:

- reduced k_{arkch}
- reduced k_{fascia} and k_{MTP}
- larger D_{lat}, which results in lower k_{CoP}
- reduced η_{chain}

Pes Cavus

Common findings include:

- reduced midfoot contact area
- concentration of loading on heel and forefoot
- relatively stable *CoP* trajectory
- reduced plantar deformation volume

These characteristics corresponded to:

- reduced k_{arch}
- neutral or slightly increased k_{fascia} and k_{MTP}
- relatively preserved k_{CoP}
- reduced V_{step}

Reduced Calf Pump Function

Studies report:

- reduced ejection fraction
- prolonged venous refilling time
- reduced flow velocity
- impaired valve competence

These characteristics were modeled through:

- reduced η_{foot}
- reduced η_{valve}
- reduced venous elasticity parameter η_{venous}
- reduced V_{step}

After parameter assignment, model outputs were normalized to the normal-arch baseline.

RESULTS

Baseline Output (Normal Arch)

Using the calibrated normal-arch parameter set, the model generated:

Q_{normal}=1.00

This value served as the reference for all comparisons.

Pes Planus

In the pes planus condition, reductions in arch stiffness, plantar fascia efficiency, windlass function, and kinematic-chain efficiency, combined with greater mediolateral *CoP* variability, resulted in:

Q_{planus}=0.65

This corresponds to a venous flow that is 35% lower than the normalized healthy reference.

Pes Cavus

Under pes cavus parameters—reduced contact-area–dependent venous filling, preserved *CoP* stability, and altered arch mechanics—the model produced:

Q_{cavus}=0.80

This represents a 20% reduction relative to the normal reference value.

Reduced Calf Muscle Pump

Simulating impaired calf pump function produced:

$Q_{calf\text{-}reduced}$=0.50 which corresponds to a 50% reduction in venous flow.

Summary Table

To contextualize the model's performance across clinically relevant foot morphologies, a summary table was constructed (Table 2). The table juxtaposes normalized venous flow outputs with well-established mechanical and hemodynamic patterns described in the literature. Demonstrating agreement between expected biomechanical deviations and model-predicted flow alterations provides qualitative support for the model's physiological validity.

Table 2. Summary of normalized venous flow and biomechanical consistency across clinical scenarios

Clinical Scenario	Relative Model Q(Normalized)	Expected Mechanical/Hemodynamic Findings in Literature	Scientific Consistency
Normal Arch	1.00	Reference venous pump output	Fully consistent with model calibration
Pes Planus	0.65	Medially shifted *CoP*, increased loading, reduced pump efficiency	Medially shifted *CoP*, increased loading, reduced pump efficiency
Pes Cavus	0.80	Medially shifted *CoP*, increased loading, reduced pump efficiency	Consistent with the expected "stable but low-volume" pattern
Reduced Calf Pump Function	0.50	Consistent with the expected "stable but low-volume" pattern	Parallel to increased stabilizing demand and reduced pump output

Graphical Output

To visually summarize the model's behavior across the evaluated clinical scenarios, normalized venous flow values were plotted as a line graph (Figure 2). This visualization enables direct comparison between model-predicted outputs and literature-based mechanical/hemodynamic expectations. The convergence or divergence of these curves highlights how deviations in arch mechanics, *CoP* stability, and pump efficiency influence overall venous return. The graphical representation therefore provides an intuitive, cross-scenario overview before the detailed interpretation presented in the following sections.

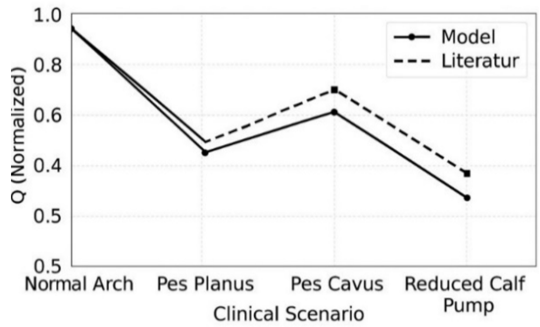

Figure 2. Normalized venous flow output generated by the model for each clinical scenario. The figure presents normalized model output for comparative illustration without direct clinical interpretation. Each condition represents an independent clinical scenario rather than a temporal progression within a single subject. All variables shown are schematic representations intended to illustrate model structure rather than patient-specific measurements.

DISCUSSION

This study proposes a novel and integrative hemodynamic–mechanical model that advances beyond the traditional framework in which lower-limb venous return is explained almost exclusively through the calf muscle pump. By incorporating the plantar venous pump, foot mechanics, kinematic chain alignment, mediolateral Center of Pressure (*CoP*) deviation, and venous valve and wall properties into a single mathematical structure, the model consolidates mechanical and hemodynamic determinants of venous flow. Whereas plantar pump function, arch morphology, calf pump efficiency, and *CoP* dynamics have largely been examined as isolated or phenomenological concepts in the existing literature, the present model analytically unifies these components through dimensionless coefficients that directly scale venous flow (Q). Particularly innovative contributions include the non-dimensionalization of *CoP* deviation (D_{lat}), its exponential efficiency term $k_{CoP} = e^{-\beta D_{lat}}$ linking *CoP* behavior to venous stroke volume (V_{step}), and the partitioning of muscle moments into stabilizing ($\tau_{stability}$) and pumping (τ_{pump}) components.

The combined use of Newton–Euler moment equilibrium, Lagrangian energy landscape analysis, and Hamiltonian phase-space formulation strengthens the mechanistic foundation of the model. As *CoP* shifts laterally, the moment arm increases and the required stabilizing torque rises, reducing the torque available for venous pumping within the fixed total muscular capacity. This reduction translates into loss of pump efficiency and diminished V_{step}. The Lagrangian formulation illustrates that increases in D_{lat} steepen the effective stiffness landscape $k_{eff}(D_{lat})$ and shift the equilibrium angle $q_{eq}(D_{lat})$, whereas the Hamiltonian perspective demonstrates that the system is driven toward higher-energy trajectories. Collectively, these analyses quantify the competition between "energy spent for stability" and "energy available for pumping," transforming what has previously been an abstract clinical intuition into an explicit mechanical mechanism.

Findings from the literature-based preliminary validation further support the directional sensitivity of the model across clinically distinct scenarios, in agreement with previous plethysmographic, pedobarographic, and Doppler-based studies. The reference case (Q_{normal}), calibrated for individuals with a normal arch profile, aligns well with plethysmographic and Doppler parameters reported in healthy populations. In pes planus, decreases in k_{arch}, k_{fascia}, k_{MTP} , and especially in k_{CoP} due to increased mediolateral deviation produced a substantial reduction in Q—consistent with reported decreases in ejection fraction, impaired emptying patterns, and greater venous reflux in flat-footed individuals. These findings emphasize that arch collapse is not merely a static morphological deviation but a dynamic perturbation that alters plantar venous reservoir filling/emptying and reorganizes pump kinetics.

In pes cavus, despite the disadvantage of reduced contact area and lower V_{step}, the relative preservation of k_{CoP} and η_{chain} due to a more stable CoP path resulted in a smaller reduction in Q, reflecting the "stable but low-volume pump" pattern commonly reported in the literature. Similarly, in conditions of calf pump impairment, reductions in η_{foot}, η_{valve}, and η_{venous} generated marked declines in Q that aligned with observed decreases in ejection fraction and prolonged refilling times. These outcomes indicate that the model does not treat the plantar and calf pumps as competing systems but rather as mechanically serial and physiologically complementary components of a unified venous return mechanism.

This comprehensive structure provides a strong conceptual basis for clinical applications. Interventions such as medial arch supports, lateral wedges, rocker-bottom footwear, and custom orthoses map directly onto V_{step}, k_{arch}, k_{CoP} and η_{foot}, enabling quantitative predictions rather than anecdotal assumptions. Likewise, strengthening exercises and gait-training protocols can be reframed not only in terms of torque production or functional capacity but also through improvements in η_{chain} and η_{foot}, linking musculoskeletal rehabilitation directly to venous pump efficiency.

Nonetheless, several limitations must be acknowledged. First, validation relied on summary statistics extracted from independent studies; simultaneous acquisition of pedobarography, gait analysis, Doppler ultrasound, and plethysmography within the same cohort remains necessary for patient-specific calibration. Second, the model currently represents the limb unilaterally, whereas real-world gait involves bilateral interactions, compensatory strategies, and trunk dynamics. Third, vessel-wall biomechanics—including nonlinear elasticity and viscoelasticity—are embedded within a single term (η_{venous}), and detailed vascular modeling remains outside the present scope.

Despite these limitations, the proposed framework translates fragmented empirical findings into a rigorous mathematical language, offering a productive platform for both basic science and clinical research. Future work should focus on calibrating parameters such as D_{lat}, k_{CoP}, k_{arch}, and the η-coefficients using measurable proxies in prospective cohorts, followed by evaluating predictive accuracy for venous flow, ejection fraction, refilling time, and symptom measures using ROC curves, error metrics, and sensitivity-specificity analyses. Embedding the model into orthotic design software, rehabilitation planning systems, or wearable-sensor decision-support platforms may ultimately pave the way toward "venous-pump-oriented personalized mechanical therapy."

CONCLUSION

The proposed model provides a quantitative mechanical explanation for how plantar mechanics, kinematic alignment, and Center of Pressure (*CoP*) behavior collectively influence lower-limb venous return by modulating step-dependent venous stroke volume and overall system efficiency through dimensionless biomechanical coefficients.

The model successfully reproduced expected directional changes in venous output across key clinical scenarios—normal arch, pes planus, pes cavus, and calf pump insufficiency—demonstrating consistency with reported plethysmography, Doppler, and pedobarography findings. These results indicate that the model is not only theoretically sound but also clinically relevant, providing a mechanistic explanation for how variations in plantar loading, arch morphology, *CoP* behavior, and muscle function collectively influence venous pump efficacy.

Beyond its theoretical significance, the framework offers a quantitative basis for evaluating the mechanical impact of orthotic design, footwear modification, strengthening programs, and gait retraining on venous hemodynamics. Future work combining pedobarography, gait analysis, Doppler ultrasonography, and plethysmography within unified experimental protocols will enable patient-specific calibration of model parameters and facilitate the development of standardized clinical assessment tools grounded in venous pump mechanics.

Overall, this study presents a coherent and expandable model that bridges biomechanics and hemodynamics, offering a promising foundation for future experimental, clinical, and interventional research aimed at optimizing lower-limb venous function.

Ethics Committee Approval: This study did not involve human participants or animal subjects; therefore, ethics committee approval was not required.

Informed Consent: None

Peer-review: Externally peer-reviewed.

Author Contributions: This work was conducted solely by the author. The development of the research concept, formulation of the theoretical framework, and design of the integrated mechanics–hemodynamics model were carried out by the author. All mathematical derivations, methodological design, parameter definitions, computational analyses, and model validation procedures were performed independently by the author. The author was also responsible for the literature review, data organization, preparation of all figures and graphical materials, interpretation of the results, and writing of the manuscript. Scientific and technical revision of the full text, as well as the final approval of the manuscript for submission, were completed solely by the author.

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Research Article

EVALUATION OF READABILITY LEVELS OF ONLINE HALLUX VALGUS CONTENT

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Keywords

Comprehension,
Hallux valgus,
Health literacy,
Internet,
Readability.

ABSTRACT

Purpose: This study aimed to evaluate the readability levels of Turkish web-based information related to hallux valgus, a common forefoot deformity. **Methods:** A descriptive content analysis was conducted. Using the keyword "Halluks Valgus," Turkish web pages accessible via Google Turkey were screened in November 2025. Among the first 97 search results, 46 eligible pages containing textual health information were included based on predefined criteria. Readability levels were assessed using the Ateşman Readability Index. Each text was analyzed through an online tool to obtain structural linguistic metrics, and readability scores were classified according to the Ateşman scale. Descriptive statistics were calculated using IBM SPSS 25.0.
Results: Among the included online sources, 44.7% were authored by physicians, 36.2% by hospitals, and 19.1% by other providers. Author information was available in 66% of the content, while 72.3% of pages were up-to-date. The mean Ateşman score was 57.91±6.04, indicating a moderate difficulty level. Overall, 89.4% of texts were categorized as moderately difficult, 2.1% as easy, and 8.5% as difficult. More than half of the content corresponded to an 11th–12th grade reading level.
Conclusion: Turkish online materials on hallux valgus generally require a high reading level and exhibit moderate readability. The frequent use of technical terminology and long sentence structures may limit accessibility for individuals with low health literacy. Improving clarity, simplifying language, and ensuring regular content updates may enhance the effectiveness and usability of digital health communication.

INTRODUCTION

Hallux valgus, a deformity characterized by lateral deviation of the big toe and structural deterioration of the first metatarsophalangeal joint, is a common forefoot deformity. It is a common orthopedic pathology affecting 19% of adults worldwide (1). The prevalence of the disease increases with age, with higher rates reported in women (2). The progressive nature of clinical symptoms increases individuals' search for information about treatment alternatives, nonsurgical approaches, and self-management strategies. A 2023 study found that Google search results related to hallux valgus and its treatments may lack transparency and quality (3).

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Therefore, the understandable and reliable nature of the initial information individuals obtain online is crucial for accurate guidance and early healthcare consultation.

Readability is a characteristic that defines the degree to which a text can be easily, fluently, and accurately comprehended by the reader through its language and structure (10). In the healthcare field, readability plays a crucial role in individuals' ability to understand, evaluate, and make informed decisions about health-related information. Low health literacy can lead to difficulties in understanding texts containing technical terms or complex structures. This can also lead to misinterpretation of information and delays in seeking healthcare services. National studies conducted in Turkey indicate that health literacy is insufficient for a large portion of the population (11). Therefore, preparing online health content at a level understandable to a wide audience has become essential for accurate and effective information delivery.

In the field of health communication, many tools have been developed and are widely used to measure the readability of digital content. The Ateşman, Bezirci-Yılmaz, and Çetinkaya-Uzun readability formulas, frequently used for Turkish texts, allow for systematic and objective assessment of comprehensibility using measurable criteria such as average word length, sentence structure, and grammatical features (12-14). Although the literature on occupational therapy (15) has examined the readability levels of online information resources for various conditions, such as tinnitus (16), hoarseness (17), scoliosis (18), dizziness (19), osteoarthritis (20), and carpal tunnel (21), it reveals that most online texts have a moderate or difficult readability level and largely require a high school education level or higher.

The internet is one of the most widely used patient resources for health information (4). Because it provides fast, up-to-date, easy-to-access, and rich information, the internet is an indispensable part of research. Web-based content is widely used by patients, their families, and healthcare professionals (5,6). However, the information it provides has limitations, such as being factually inaccurate, biased by the industry, and/or lacking peer review (7). Furthermore, the quality, accuracy, suitability for the target audience, and readability of online health information can vary significantly (8,9). Content with low readability can make it difficult for individuals to accurately understand illness, evaluate treatment options, and guide health behaviors. Therefore, the understandability of health information presented digitally is a fundamental component of effective health literacy.

In this study, we focused on web-based information sources related to hallux valgus, one of the most common disorders of the big toe. The quality and accuracy of online information were assessed through independent searches using the keywords "halluks valgus". The findings will reveal the understandability of the content of web-based information sources and provide guidance for future web-based health content developers. This will help make digital health communication more accessible and effective.

METHODS

Purpose and Type of Research

This study is a descriptive content analysis that aims to examine the readability levels of online content. Turkish web pages accessible through the Google search engine were systematically searched using the keyword "Halluks Valgus."

Population and Sample of the Study

A search was conducted using the Google Turkey search engine (www.google.com.tr) in November 2025. The first 97 web pages listed in the search results were scanned; a total of 46 pages that met the inclusion criteria were evaluated. Only pages containing textual content and intended to provide health information were included in the study. Pages containing video/visual content, text shorter than 10 sentences, forum/blog/social media-based pages, pages that cannot be copied or with restricted access, and pages generated by artificial intelligence or that serve as referrals were excluded. The eligibility assessment was conducted by two independent researchers, and in cases of disagreement, the consensus method was used.

Ethical Aspects of the Research

Because this study relies on the analysis of publicly available web-based digital content, it does not involve any intervention on any individual and does not collect personal data. Therefore, ethics committee approval is not required. The principles of scientific research and publication ethics were meticulously observed throughout the research.

Data Collection and Analysis

The readability levels of the web pages were assessed using the Ateşman Readability Index. The text of each page was imported into the online tool okunabilirlikindeksi.com, and sentence length, total word count, and average syllable count per word were calculated. The Ateşman Readability Index is an adapted version of the Flesch Reading Ease formula, which determines the readability of Turkish texts. Scores were categorized as “very easy” (90–100), “easy” (70–89), “medium” (50–69), “difficult” (30–49), and “very difficult” (0–29). Data distribution was assessed using the Shapiro–Wilk test, and descriptive statistics (mean, standard deviation, minimum, and maximum) were analyzed using IBM SPSS Statistics 25.0.

RESULTS

When the provider types of 46 online contents examined in the study on Hallux valgus were examined, it was determined that 44.7% of the contents were provided by doctors, 36.2% by hospitals, and 19.1% by other sources (Figure 1).

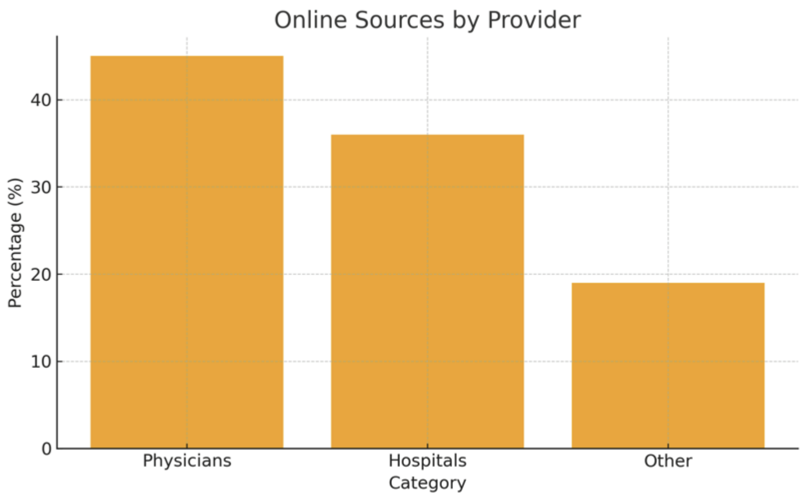

Figure 1. Providers of Online Resources

An examination of the accessibility of author information on web pages revealed that 66% of the content clearly identified the author, while 34% contained no author information at all. When the content was evaluated for currency, it was determined that 72.3% of the pages contained up-to-date information, while 27.7% were outdated or did not specify an update date. It was revealed that the most updates related to hallux valgus were made in 2025, 2023, and 2025, respectively.

Descriptive statistics for the analyzed texts, including word count, character count, difficult word count, unique word count, sentence count, paragraph count, average word length, and average sentence length, are presented in Table 1.

Table 1. Descriptive statistics on the analyzed texts

	Minimum	Maximum	Mean ± Standard Deviation
Word Count	52	3242	823.77 ± 672.59
Number of Characters	413	26022	6611.45 ± 5409.06
Number of Difficult Words	52	3210	814.74 ± 665.06
Number of Unique Words	43	1385	462.06 ± 298.69
Number of Short Words	6	427	114.32 ± 94.63
Number of Characters Without Spaces	361	22587	5968.57 ± 5136.20
Number of Sentences	6	406	83.34 ± 74.78
Number of Paragraphs	1	242	42.98 ± 24.79
Average Word Length	2.68	3.17	2.83 ± 0.11
Average Sentence Length	6.5	17.1	10.42 ± 2.26
Ateşman Readability Index	44.90	72.60	57.91 ± 6.04

According to the Ateşman Readability Index, 2.1% of the texts on the examined web pages on hallux valgus were found to be "easy" (7th-8th grade level), 89.4% were "medium" difficulty (9th-10th and especially 11th-12th grade level), and 8.5% were "difficult" (13th-14th grade level). When the educational level classification was evaluated, it was seen that 55.3% of the texts corresponded to the 11th-12th grade level (Figure 2).

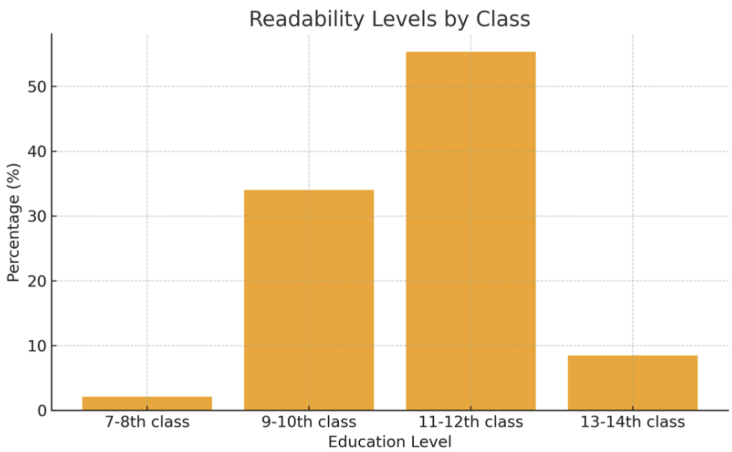

Figure 1. Readability Levels of Texts According to Ateşman (By Class)

DISCUSSION

The hallux valgus content examined in this study had a readability level of medium difficulty according to the Ateşman and Çetinkaya-Uzun indices. For example, 89.4% of the content was in the moderate category according to Ateşman, only 2.1% was in the easy category, and the average Ateşman score was approximately 58 (above high school level). These findings are consistent with results from similar studies. An international study reported that the overall quality of online information about hallux valgus was low and written at a very high reading level (22). A study from Turkey emphasized that online content on scoliosis was mostly of medium difficulty (Ateşman mean score: 56.7) and geared towards high school level students, but that understanding needs to be improved for a wider audience (18). Systematic reviews indicate that patient education materials frequently exceed recommended reading levels, and much of the health information content uses complex language that is incomprehensible to the general readership (23).

The findings of our study present significant risks for individuals with low health literacy. These individuals may have difficulty understanding texts filled with long, complex sentence structures and medical terminology; this can lead to misinterpretation of information, delay of treatment decisions, or the development of inappropriate health behaviors. Sentell and Halpin demonstrated that low health literacy levels negatively impact individuals' ability to access, understand, and use health information to make informed decisions (24). In this context, it is crucial that digital health content be designed in a clear, concise manner, and appropriate to the target audience's comprehension level. In online informative content for common conditions such as hallux valgus, simplifying medical terminology, supporting it with short and understandable sentences, and enriching it with visuals if necessary will facilitate access to information.

The sources of content in our study exhibited similar trends. Healthcare providers (private hospitals, physicians) provided the majority of the sources; author information was missing in 34% of the content, and update dates were not provided in 28%. This reflects a problem highlighted by previous research. Tartaglione and colleagues noted that while physician-authored web content is more accurate than other sources, it is more difficult to read (22). Our findings also indicate that professionally prepared health information resources have a high reading level. While this increases the technical accuracy of the content, it can reduce its accessibility to the broader public.

One of the distinguishing features of this study is that, despite Hallux Valgus being a highly prevalent deformity, the language used in digital content still contains highly technical terms, which limits its understandability. The presentation of terms from physiotherapy, surgery, and orthopedics, in particular, without explanation, increases the medical accuracy of the texts but makes them difficult for the general public to access. Because Hallux Valgus is related to both the musculoskeletal system and motor functions, the use of multidisciplinary language is necessary. However, presenting this language without simplification can prevent individuals, especially those with low health literacy, from accessing accurate information.

Limitations of the Study

This study has several limitations that should be acknowledged. First, the data were collected exclusively through the Google Turkey search engine, and other commonly used platforms such as alternative search engines or social media–based information sources were not included. This may have limited the diversity and representativeness of the examined online content. Second, only Turkish-language materials were analyzed; therefore, the findings cannot be generalized to online resources presented in other languages. Third, the study focused solely on publicly accessible textual information, excluding videos, visual-based materials, subscription-restricted pages, and user-generated content such as forums or social media comments. As a result, some potentially relevant sources may not have been captured. Future studies may benefit from incorporating user experience assessments, qualitative evaluations, and broader platform sampling to provide a more comprehensive understanding of online health information readability.

CONCLUSION

This study revealed that the majority of Turkish online materials related to hallux valgus are written at a moderate readability level according to the Ateşman Readability Index, corresponding predominantly to the 11th–12th grade education level. The high proportion of moderately difficult texts suggests that current online resources may not be fully accessible to individuals with low health literacy. In addition, the limited presence of author information and the insufficient reporting of update dates raise concerns regarding the transparency and currency of the available content.

Given the widespread use of the Internet as a primary source of health information, the readability and clarity of digital materials play a critical role in supporting accurate patient understanding and informed decision-making. The complexity introduced by medical terminology, lengthy sentence structures, and insufficient explanations may hinder comprehension, particularly among vulnerable populations. Therefore, efforts to simplify language, enhance structural clarity, and incorporate supportive visual elements are essential for improving the accessibility of online patient education materials.

This study highlights the need for standardized guidelines for the development of digital health content in Turkey. Collaboration between healthcare professionals and communication specialists may facilitate the creation of accurate, comprehensible, and user-friendly resources. Regular content updates, clear authorship, and adherence to readability criteria will further strengthen the reliability and effectiveness of online health information.

Ethics Committee Approval: This study does not require ethics committee approval, as it is based on the analysis of publicly available online content and employs a descriptive content analysis method. However, it was conducted in accordance with ethical research principles.

Informed Consent: Not required as the study was based on publicly available online data.

Peer-review: Externally peer-reviewed.

Author Contributions: EÖ: Conception, design, data collection, analysis/interpretation, literatüre review, writing, critical review. GKK: Conception, design, data collection, writing, critical review.

Conflict of Interest: The authors report there are no competing interests to declare.

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Research Article

CAREER INTENTIONS AND CLINICAL EXPOSURE IN AMPUTEE REHABILITATION AND PROSTHETICS AND ORTHOTICS AMONG TURKISH PHYSIOTHERAPY STUDENTS

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Keywords

Amputees,
Physical therapy
Education,
Prosthetics and orthotics.

ABSTRACT

Purpose: This study aimed to assess the career preferences and self-perceived competence of fourth-year physiotherapy students in Türkiye regarding amputee rehabilitation and prosthetics/orthotics.
Methods: A cross-sectional survey was conducted among 220 fourth-year physiotherapy students from seven universities in Türkiye. The survey evaluated students' interest in pursuing careers in amputee rehabilitation and prosthetics/orthotics, their clinical exposure to amputee patients, and their self-perceived competence in these specialized fields.
Results: Over 50% of the surveyed students expressed no intention to work in amputee rehabilitation or prosthetics/orthotics after graduation. Most students reported observing fewer than three amputee patients during their education, indicating limited clinical exposure. Despite increased interest following the 2023 earthquake in Türkiye, 81.8% of students felt incompetent to participate in post-earthquake amputee rehabilitation.
Conclusion: The findings indicate insufficient clinical exposure in these fields, which may contribute to low perceived competence and limited career intentions. These findings emphasize the need for curriculum reforms and strategies to increase structured clinical exposure, such as systematic placements and collaborations with prosthetics and orthotics clinics, to enhance students' competence and confidence in amputee care and rehabilitation.

INTRODUCTION

Amputation is an irreversible major surgical procedure that affects not only the physical functioning of an individual but also deeply impacts psychological integrity, social roles, and quality of life (1, 2). In Türkiye and worldwide, the major causes of amputation are diabetes, peripheral vascular disease, cancer, and traumatic events (3, 4). In addition to these chronic conditions, increasing geopolitical instability and conflicts, and recent natural disasters have turned amputations into a global health crisis (5, 6). On February 6, 2023, a major earthquake affected the eastern and southeastern parts of Türkiye, resulting in approximately 120,000 people injured (7). According to early reports in March 2023, 850 people underwent amputation due to trauma resulting from the earthquake, and this number is expected to increase (7). This disaster has tragically highlighted the great need for competent healthcare professionals in the field of prosthetics and orthotics, and amputees to manage complicated limb loss and rehabilitation processes.

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Care for amputees does not end with the surgical procedure; rather, it requires a complex and multidisciplinary rehabilitation process (8). This process starts with preoperative care and extends to lifelong psychosocial support, including prosthetics and rehabilitation (8). Physiotherapists are the core element of this multidisciplinary team and play a key role in increasing the functional independence of individuals and supporting their reintegration into society (9). The role of physiotherapists extends beyond prescribing exercises and includes adaptation to prosthetics and coping with challenges in daily life (10).

To achieve this qualification in the amputee care and prosthetics orthotics field, structured education is required to equip professionals with a fundamental understanding of these patients. Accordingly, the Physiotherapy and Rehabilitation National Core Training Program (FTR-UÇEP 2025) in Türkiye requires graduates to master the fundamental principles of postamputation rehabilitation as an educational standard (11). However, the extent to which this theoretical standard is met in practice remains a critical question. International literature demonstrates that when theoretical training in a specific field is not supported by adequate clinical exposure, students' self-confidence and professional preparation levels decline significantly (12, 13).

Therefore, the main purpose of this study was to scientifically examine the extent to which fourth-year students studying in the Physiotherapy and Rehabilitation Departments of universities in Türkiye consider pursuing amputee rehabilitation and orthosis/prosthesis applications in their post-graduation career planning and the factors affecting these tendencies.

METHODS

This descriptive, cross-sectional study investigated pre-graduate tendencies of physiotherapy and rehabilitation department bachelor's degree students toward working in the field of prosthetics and orthotics application and amputee rehabilitation.

This study was approved by the Trakya University Faculty of Medicine Non-Interventional Scientific Research Ethics Committee (TÜTF-GOBAEK 2025/428). The survey included a digital "Informed Consent Form" that detailed the study's purpose, procedures, data confidentiality, and anonymity. Participants accessed the survey questions after digitally approving the consent form.

Participants

Participants were 4^{th}-grade physiotherapy and rehabilitation department students in the 2025-2026 academic year who volunteered to participate in the study and had adequate proficiency in Turkish to understand and reply to the survey questions. Participants were invited via online methods, such as bulletin boards, social media, and class groups. Two hundred and twenty students who were over 18 years of age, actively pursuing undergraduate education, and who provided informed consent participated in the study.

Assessment

Data were collected using an online questionnaire developed by the researchers for purposes of this study. The online questionnaire consisted of questions regarding demographic information, including age, gender, and university, and questions aimed at assessing the tendency to work in the prosthetics and orthotics field post-graduation, opportunity to observe amputee rehabilitation or prosthetics and orthotics applications in clinical practice, effects of earthquakes on intention and competency perception, and intention of voluntary clinical internship in prosthetics and orthotics application center (Appendix 1).

Statistical Analysis

The sample selection was conducted using the convenience sampling method. The sample size was determined based on the number of voluntary participants reached during the study period, with the aim of maximizing the sample to ensure adequate representation of the target population. Statistical analyses were performed using SPSS v25.0 (IBM Corp.). Descriptive statistics were presented as mean ± standard deviation, and categorical results were presented as numbers (n) and percentages (%).

RESULTS

The demographic characteristics, career orientations, clinical experiences, and self-efficacy perceptions of the 220 students from seven universities across four different geographical regions of Türkiye are summarized below. The participating institutions included Trakya and Kırklareli Universities (Marmara Region), Aydın Adnan Menderes and Muğla Sıtkı Koçman Universities (Aegean Region), Kırıkkale and Sivas Cumhuriyet Universities (Central Anatolia Region), and Bolu Abant İzzet Baysal University (Black Sea Region). The mean age of the participants was 21.86±1.36, and 77.7% (n=171) were female and 22.3% (n=49) were male.

When students' post-graduation career plans were examined, it was observed that the field of prosthetics and orthotics and amputee rehabilitation was not a popular choice among physiotherapy students (Table 1). More than 50% of the participants did not intend to pursue prosthetics and orthotics applications and amputee rehabilitation after graduation.

The clinical practice experience of students in the field of prosthetics and orthotics applications and amputee rehabilitation was found to be very limited. Moreover, more than 50% of the participants did not encounter amputee patients or prosthetics and orthotics application during education, and 65% of them did not observe the rehabilitation process of an amputee in clinical practice. In the clinical setting, less than 10% of participants had the opportunity to observe the amputee rehabilitation process of more than three patients, and less than 15% had the opportunity to observe prosthetics and orthotics applications on more than three patients in clinical practice. Only one participant performed a voluntary clinical internship at a prosthetics and orthotics application center, and almost 80% of the participants were indecisive or did not consider doing a clinical internship at a prosthetics and orthotics application center. Approximately 30% of the participants had attended a seminar, congress, or course on prosthetics and orthotics applications topic before (Table 1).

One of the most striking findings of this study is the paradox between increased interest and lower self-efficacy perceptions following the earthquake (Table 1). Forty percent of the participants stated that the earthquake positively impacted their interest in this field. However, this increased motivation was not reflected in their professional self-confidence levels. The overwhelming majority of participants (81.8%) believed that they lacked the competence to function effectively in this field.

Table 1. Post-Graduation Career Intentions and Clinical Education Experiences

	Yes n (%)	**No n (%)**	**Indecisive n (%)**	
Are you considering pursuing amputee rehabilitation after graduation?	10 (4.5%)	120 (54.5%)	90 (40.9%)	
Are you considering pursuing a career in prosthetics and orthotics applications after graduation?	15 (6.8%)	118 (53.6%)	87 (39.5%)	
Have you encountered any amputee patients in your immediate circle?	96 (43.8%)	123 (56.2%)	-	
Did you have the opportunity to observe and apply amputee rehabilitation practices during your training?	76 (34.5%)	144 (65.5%)	-	
Did you have the opportunity to observe/practice prosthetic/orthotic rehabilitation practices during your training?	103 (46.8%)	117 (53.2%)	-	
Have you ever volunteered for an internship at a prosthetic/orthotic application center?	1 (0.5%)	219 (99.5%)	-	
Are you considering a volunteer internship at a prosthetic/orthotic application center?	47 (21.4%)	76 (34.5%)	97 (44.1%)	
Do you feel competent to take part in post-earthquake amputee rehabilitation?	40 (18.2%)	180 (81.8%)		
	Did not changed	**Changed positively**	**Changed negatively**	
Has your preference for amputee rehabilitation changed after the earthquake?	131 (59.5%)	88 (40%)	1 (0.5%)	
	0-3 Patient, n (%)	**3-6 Patient, n (%)**	**6-10 Patient, n (%)**	**10+ Patient, n (%)**
How many patients did you have the opportunity to observe/apply amputee rehabilitation practices during your training?	205 (93.6%)	10 (4.6%)	2 (0.9%)	2 (0.9%)
During your training, how many patients did you have the opportunity to observe/apply prosthetic/orthotic rehabilitation practices?	191 (87.2%)	16 (7.3%)	10 (4.6%)	2 (0.9%)
	Seminar, n (%)	**Course, n (%)**	**Congress, n (%)**	**Other, n (%)**
Have you ever participated in any prosthetic/orthotic-related activities?	52 (24.0%)	2 (0.9%)	11 (5.1%)	152 (70.0%)

DISCUSSION

The study's findings indicate that, despite the increasing need, candidate physiotherapists have a low interest in working in the field of prosthetics and orthotics application or amputee rehabilitation. The limitations of students' observation/practice opportunities within the scope of clinical practice in the field of prosthetics and orthotics application or amputee rehabilitation seem to be the reason for the disconnection between the specialized manpower required in the field of amputee rehabilitation and students' interest in working in the field.

Our findings show that only 4.5% of students had a clear intention to work in the field of amputee rehabilitation, compared to 54.5% showing no interest and 40.9% being indecisive. Similarly, only 6.8% of students had a clear intention to work in prosthetics and orthotics, compared to 53.6% showing no interest and 39.5% being indecisive. These findings are in line with previous literature, which indicates that the majority of physiotherapy students have a tendency to work in the more popular fields like musculoskeletal rehabilitation or sports physiotherapy rather than more specialized fields like pediatrics, geriatrics, or prosthetics/orthotics (14). This reluctance to enter the prosthetics and orthotics field is not unique to Türkiye, previous studies similarly noted that physiotherapy students globally prefer more popular fields like musculoskeletal or sports rehabilitation instead of prosthetics and orthotics as a 'niche' specialization requiring distinct technical skills that differ from the manual therapy-focused curriculum they are comfortable with (15, 16). Additionally, the career intention tendencies of physiotherapy are mostly determined by the most encountered subjects during undergraduate education and clinical practice (17, 18). The field of prosthetics and orthotics might be perceived by students as uninviting due to its complicated biomechanical nature and need for following advanced technology related to the field, combined with inadequate educational and clinical background. Therefore, students' lack of interest in this field may be a reflection of the opportunities they have in educational curriculum and clinical practice and present it as an attractive career path, rather than a personal preference.

Results of this study showed that after the earthquake centered in Kahramanmaraş, Türkiye in February 2023, 40% of the students changed their preference to work in the field positively indicating a formation of awareness and sense of social responsibility. However, a great majority of students (81.8%) did not feel competent to take part in post-earthquake amputee rehabilitation, which further indicates that this motivational change does not translate into a perception of competence. The disparity between high motivation and low self-efficacy following the earthquake highlights a critical gap in disaster preparedness within the current curriculum. This aligns with broader literature on healthcare students' disaster readiness; for instance (19, 20), emphasized that while students often feel a moral duty to help during disasters, they lack the technical confidence to do so. This might be due to the fact that almost 9 out of 10 student cannot gain sufficient clinical experience by seeing only 0-3 patients during their education. Since self-efficacy perception is an essential part of career exploration and decision-making (21), it is not surprising that students with low competency due to inadequate clinical experience do not intend to work in the field of amputee rehabilitation or prosthetics and orthotics.

Although the Physiotherapy and Rehabilitation National Core Training Program (FTR-UÇEP 2025) presents the competencies in the field that graduates should have as a framework (11), our study demonstrates that these competencies remain on paper and there are serious gaps in their transfer to real clinical practice. Considering the increasing need in the field of amputee rehabilitation and prosthetics and orthotics (22), this situation emphasizes the need to take concrete steps to solve the gap between the theoretical framework and education process.

The lack of voluntary internships observed in our sample is particularly concerning when viewed through the lens of 'situated learning theory,' which suggests that professional identity is formed through participation in real-world communities of practice (23). Without the 'legitimate peripheral participation' that occurs during a prosthetics and orthotics internship, students cannot visualize themselves in this role. Our results reinforce the argument that observation alone is insufficient; active participation in prosthetics and orthotics clinics is required to transform theoretical knowledge into professional confidence.

Limitations of the Study

This study has limitations regarding the generalizability of its results to all physiotherapy students in Türkiye due to the sample used. Future research should focus on qualitative research methods, such as interviews and focus groups, to understand the in-depth reasons behind students' avoidance of this field. Additionally, multicenter studies comparing the competency levels and career choices of students at universities implementing different curricular models (e.g., with and without mandatory prosthetics and orthotics internships) would provide compelling evidence to assess the effectiveness of curricular reforms.

CONCLUSION

This study has shown that physiotherapy students in Türkiye have low career interest in the field of amputee rehabilitation and prosthetics and orthotics, and that their clinical experience and exposure opportunities are quite limited. A potential reason for this low career interest is largely attributed to a low sense of self-efficacy due to insufficient clinical experience. Despite the positive changes in students' attitudes toward the field, particularly after the 2023 earthquake, this low sense of competence highlights the need to restructure undergraduate physiotherapy programs, particularly their clinical training components, in an evidence-based and needs-focused manner to cultivate a qualified workforce capable of meeting Türkiye's growing rehabilitation needs in the field.

Ethics Committee Approval: Non-Interventional Scientific Research Ethics Committee of Trakya University (TÜTF-GOBAEK 2025/428).

Informed Consent: Informed consent was obtained from all patients for being included in the study.

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Research Article

INVESTIGATION OF PARENTAL EXPECTATIONS REGARDING ANKLE–FOOT ORTHOSIS USE IN CHILDREN DIAGNOSED WITH CEREBRAL PALSY: THE CASE OF ŞANLIURFA PROVINCE

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Keywords

Ankle–foot orthosis,
Cerebral palsy,
Family expectations,
Orthosis compliance,
Pediatric rehabilitation.

ABSTRACT

Purpose: The aim of this study was to evaluate the expectations of families of children with cerebral palsy (CP) who use ankle–foot orthoses (AFOs). Additionally, demographic characteristics of children with CP, socioeconomic status of their families, awareness levels regarding CP, expectations from treatment and orthosis use, and perceptions of orthosis appropriateness were investigated.

Methods: This cross-sectional study included voluntary parents of children aged 3–18 years with a diagnosis of CP who had been using an AFO for at least four months and were receiving treatment at special education and rehabilitation centers in Şanlıurfa, Türkiye. A total of 120 parents participated. Data were collected using a researcher-developed Parent Questionnaire Form including demographic information, socioeconomic status, knowledge about CP and orthosis use, orthosis compliance, satisfaction, and perceived benefits. Descriptive statistics and appropriate parametric and non-parametric analyses were performed using SPSS software.

Results: Night AFOs were used significantly longer than walking AFOs ($p < 0.05$). The majority of children (79.19%) used their orthoses regularly. The most commonly reported reasons for irregular use were discomfort, pain, sweating, and child reluctance. Parents demonstrated limited knowledge about CP and the context-dependent pain-reducing effects of AFOs, rather than a general analgesic effect. Overall, AFOs were found to meet family expectations at a moderate level.

Conclusion: Family–rehabilitation center collaboration is essential to minimize problems related to orthosis use in children with CP. Increasing parental knowledge regarding CP rehabilitation and AFO use may improve treatment compliance and outcomes. These findings may contribute to the development of clinical guidelines for physiotherapists.

INTRODUCTION

Cerebral palsy (CP) is one of the most common physical disabilities observed in early childhood. CP is defined as a permanent disorder characterized by posture impairment, loss of motor skills, and movement limitations resulting from disturbances that occur during the prenatal, perinatal, or postnatal periods (1). In CP, movement, posture, and balance are affected. Orthoses are used to support walking functions and standing abilities in children with CP.

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Children who benefit most from orthotic interventions are those with mild to moderate quadriparesis, diparesis, and spastic hemiparesis. Studies have demonstrated that children exhibit more stable movements when using orthoses. In general, the use of orthoses in children is important in terms of preventing deformities and providing support during sitting (2). One of the most commonly used orthoses to prevent postural disorders and increase mobility in CP is the ankle–foot orthosis (Ankle Foot Orthosis [AFO]) (2).

In clinical settings, physiotherapists recommend the use of AFOs for children with CP in order to improve gait parameters such as walking speed, step length, and cadence. AFOs have also been found to be highly important in improving joint movements in children (3–5). For the treatment of children with CP, the appropriate use and follow-up of orthoses are of great importance in rehabilitation. Regular use and necessary individual adjustments are essential for orthotic effectiveness. Monitoring the suitability of orthoses and variables such as family-related factors, making modifications to orthoses when necessary, and evaluating the effectiveness of orthoses are crucial for the progression of disease management. It is particularly important that orthoses designed for children are selected by taking into account the developmental changes of the child. In addition to variables such as the diagnosis, age, height, body weight, joint range of motion, and muscle strength of the child with CP, family and child expectations, perceptions regarding orthosis use, and financial resources should also be investigated, as reported in the literature (6–8).

The existing literature indicates that studies investigating family expectations regarding orthosis use in children with CP are limited and insufficient. Therefore, this study was conducted to evaluate the expectations of families of children diagnosed with CP who use ankle–foot orthoses (AFOs). Within the scope of this study, the demographic characteristics of children with CP, the socioeconomic status of their families, their levels of awareness regarding the disease, expectations from treatment and the orthosis use process, and perceptions regarding the appropriateness of the orthoses used were also examined. It is anticipated that the findings obtained from this study will contribute to the development of future guidelines for physiotherapists.

METHODS

This study was conducted to investigate the expectations of families of children with cerebral palsy (CP) who use ankle–foot orthoses (AFOs) and reside in the province of Şanlıurfa. Voluntary parents of children diagnosed with CP, aged between 3 and 18 years, who had been using an AFO for at least four months and were receiving treatment at different private special education and rehabilitation centers in Şanlıurfa were included in the study. Exclusion criteria included parents of children who: were younger than 3 years or older than 18 years, had a diagnosis other than cerebral palsy, had been using an ankle–foot orthosis for less than four months, were not receiving ongoing rehabilitation or special education services at the time of the study, had undergone orthopedic surgery or botulinum toxin injections within the previous six months, which could affect orthosis use or parental expectations, had severe cognitive or communication impairments that could limit the parents' ability to reliably report expectations related to orthosis use, whose parents were unwilling or unable to provide informed consent.

The study was approved by the Non-Interventional Research Ethics Committee of the Faculty of Health Sciences, Hasan Kalyoncu University, with the decision dated 27.04.2021 and numbered 2021/058. An informed consent and volunteer information form explaining the purpose and content of the study was presented to the participants, and written informed consent was obtained from the parents who agreed to participate in the study. The study was conducted in accordance with the Helsinki Declaration.

A power analysis was conducted to determine the sample size of the study. The minimum required sample size was calculated as at least 102 children diagnosed with CP, based on an 80% power, 95% confidence level, $\alpha = 0.05$ An a priori power analysis was conducted to estimate the required sample size. Assuming a moderate effect size (Cohen's $d = 0.5$), an alpha level of 0.05, and a statistical power of 80%, the minimum required sample size was calculated. The confidence level was set at 95%. (9). The study was completed using data obtained from 120 parents of children diagnosed with CP.

In this study, the "Parent Questionnaire Form" developed by the researchers was used as the data collection tool. The questionnaire administered to parents included questions regarding the children's demographic characteristics, parental education level, family socioeconomic status, levels of knowledge related to cerebral palsy and the purpose of orthosis use, information about rehabilitation processes, whether the children had orthosis usage habits, reasons for not using orthoses if applicable, parents' comments and criticisms regarding orthosis use, and overall family satisfaction with the orthosis. Responses to the questions were provided in yes/no, multiple-choice, and open-ended formats. For some questions, participants were asked to rate their responses using a Visual Analog Scale (VAS) ranging from 0 to 10 (with 0 indicating the lowest score and 10 indicating the highest score).

Although several clinical variables such as CP type and distribution, GMFCS level, comorbidities, spasticity severity, and AFO characteristics (e.g., solid, hinged, or ground-reaction; night-time versus walking use) may influence family expectations regarding AFO use, these variables were not systematically assessed or included in the present study. The primary focus of the study was to explore parental expectations and perceived knowledge related to AFO use, rather than to examine clinical or functional determinants of these expectations.

Statistical Analysis

The Statistical Package for the Social Sciences (SPSS) software program was used for data analysis. Analyses were expressed using frequency, percentage, mean, standard deviation, standard error, skewness, and kurtosis values. Depending on whether the data showed a normal distribution and homogeneity of variances, parametric analyses were applied. For demographic variables divided into two groups, such as yes/no or present/absent. Depending on the normality of distribution, the Paired t-test or Wilcoxon signed-rank test was applied to numerical (continuous) variables. Categorical variables (e.g., yes/no, present/absent) were analyzed using chi-square test. The study group consisted of a single group, and comparisons were made between two different conditions as sub-dimensions of a demographic characteristic within the same group. Similarly, for demographic variables with more than two categories within the same group—such as place of residence, income status, and education level—one-way analysis of variance (ANOVA) and post-hoc analyses were conducted and reported in the findings. The Chi-square Test was used to examine the distribution of qualitative data between groups. In all statistical analyses, the p-value was accepted as 0.05. Accordingly, analyses were limited to descriptive evaluations of parental expectation and knowledge scores. No stratification or adjustment based on clinical characteristics was performed (10).

RESULTS

A total of 120 children with cerebral palsy (CP), aged between 3 and 18 years (age: 91.8 ± 48.6 months; height: 118.6 ± 24.5 cm; body weight: 28.7 ± 12.8 kg), including 53 females and 67 males, were included in the study.

When the caregivers of children with CP were examined as n (%), it was observed that mothers, fathers, sisters, and brothers were involved in caregiving; however, the caregiver role was predominantly assumed by mothers (Table 1).

Table 1. Caregiver Information for Children with CP

Caregiver	n	%
Mother	93	77.5
Father	20	16.7
Sister	4	3.3
Brother	3	2.5
Total	120	100

When the sociodemographic characteristics of parents were examined, it was determined that the majority were primary school graduates, had a monthly income below 5,000 TL, predominantly resided in urban areas, and 55% had social security coverage (Table 2). The number of individuals living in the household ranged between 2 and 13, with an average of 5–6 individuals.

Table 2. Sociodemographic Characteristics of Parents

Variable	Category	n	%
Education level	**None**	17	14.17
	Primary school	76	63.33
	High school	18	15
	University	9	7.5
Monthly family income	**Below 5,000 TL**	105	87.5
	5,000–10,000 TL	14	11.67
	Above 10,000 TL	1	0.83
Place of residence	**Village**	12	10
	District	17	14.17
	City	91	75.83
Social security	**Yes**	66	55
	No	54	45

Table 3. The Characteristics of AFO Use Children with CP

Variable	n (%) / Mean ± SD
Duration of AFO use	
< 1 year	18 (15.0%)
1–4 years	91 (75.8%)
≥ 5 years	11 (9.2%)
Type of AFO used	
Night orthosis	48 (40.0%)
Walking orthosis	59 (49.17%)
Both night and walking orthoses	13 (10.83%)
Daily duration of AFO use (hours)	
Night orthosis	4.84 ± 1.97
Walking orthosis	3.85 ± 1.87

The characteristics of AFO use among children with CP are summarized in Table 3. Eighteen children had been using AFOs for less than one year, 91 children for 1–4 years, and 11 children for five years or longer. Regarding orthosis type, 48 children (40%) used night orthoses, 59 children (49.17%) used walking orthoses, and 13 children (10.83%) used both walking and night orthoses, with walking orthoses being the most frequently used type. When daily usage duration was evaluated, night orthoses were used for a longer period (4.84 ± 1.97 hours) compared to walking orthoses (3.85 ± 1.87 hours), and this difference was statistically significant ($p < 0.05$).

In the evaluation of whether children used their orthoses regularly, it was found that regular or irregular orthosis use did not differ between night and walking orthoses. However, 26.66% of the children were reported not to use their orthoses regularly. Accordingly, it was determined that 79.19% of the children used their orthoses regularly.

When parents were questioned regarding the reasons why children with CP did not use their orthoses regularly, 32 parents reported various reasons. These reasons included pain caused by the orthosis (n = 3), the orthosis pressing into the foot and causing wounds (n = 2), excessive sweating (n = 6), the child crying, being irritable, becoming bored, unwillingness, removing the orthosis when angry, lack of acceptance, inability to adapt, and discomfort (n = 18), parents being unable to allocate sufficient time to their child with CP (n = 1), and the inability to achieve the desired joint range of motion in the child with CP despite AFO use (n = 2).

Fifteen parents participating in the study reported experiencing various problems while their children with CP were using AFOs. These problems were listed as follows: "The orthosis causes pain, creates discomfort by squeezing the foot, and the child cries and does not want to use it" (5 parents); "Loss of balance and fear of falling associated with orthosis use" (1 parent); "The orthosis has become too small" (1 parent); "Sweating, pain, and minor injuries" (3 parents); "The orthosis feels heavy" (1 parent); "The child does not want to wear the orthosis" (1 parent); "The orthosis causes wounds" (1 parent); "The foot slips inside the orthosis" (1 parent); and "The orthosis hits the heel" (1 parent).

It was observed that among 72 children using walking AFOs, the orthosis was used more frequently while walking both at home (81.94%) and outdoors (61.11%), with higher usage rates observed at home.

When parents were questioned about what actions they took when problems occurred with the orthoses used by their children with CP, it was determined that the rate of taking the orthosis back to the manufacturing center was high (Table 4).

Table 4. Solutions Implemented When Problems Occurred with Children's AFOs

Orthosis-related action	n	%
Immediately taking it to the manufacturing center	67	55.83
Attempting to solve the problem themselves	10	8.33
Continuing to use it for a while and then taking it to the center	23	19.67
Doing nothing	12	10
Consulting the physiotherapist	1	0.83
Did not experience any problems	7	5.83

To evaluate both parental knowledge regarding orthoses and children's adaptation to orthosis use, parents were asked to rate their level of knowledge regarding rehabilitation, cerebral palsy, the benefits of AFO use, the purpose of orthosis use, expectations from AFOs, and the perceived effects of AFOs on body balance, deformity prevention, and context-specific pain-related outcomes (e.g., contracture-related pain, fatigue-associated discomfort, and discomfort secondary to abnormal biomechanical loading), as well as the prevention of unwanted body movements by the AFO used. Parents were asked to score these items on a scale ranging from 0 to 10. Based on these ratings, it was observed that parents had limited knowledge regarding CP, and the scores related to the context-dependent pain-relieving effects of AFOs were low (Table 5).

Table 5. Findings Related to Parental Knowledge About Orthoses and Children's Adaptation to Orthosis Use

Item	Mean	Standard Deviation	Minimum	Maximum
How much knowledge do you have about rehabilitation?	5.17	2.30	0	10
How much knowledge do you have about cerebral palsy?	4.38	2.46	0	10
How beneficial is AFO use for you?	5.51	1.89	1	10
Do you know the purpose of the orthosis being used?	5.35	2.25	0	10
To what extent does the AFO used meet expectations?	5.86	1.91	1	10
To what extent does the AFO affect body balance?	5.23	2.08	0	10
How effective is the AFO in preventing deformity (explained to the family)?	5.70	2.00	0	9
How effective is the AFO in reducing pain?	3.60	2.05	0	8
How effective is the AFO in preventing unwanted body movements?	5.45	1.86	0	9

DISCUSSION

In this study conducted to examine the expectations regarding ankle–foot orthosis (AFO) use among families of children with cerebral palsy (CP) living in the province of Şanlıurfa, it was observed that night orthoses were used more frequently than walking orthoses and that AFOs generally met family expectations to a large extent.

In recent years, the number of studies related to orthosis use has been steadily increasing. Research indicates that orthosis use combined with rehabilitation treatment processes provides significant benefits for children and positively affects their gait. In a study examining the effects of ankle–foot orthosis use on children with CP aged between 3 and 18 years, the problems experienced by parents during their children's orthosis use were investigated. Compliance with night orthoses was found to be lower than compliance with daytime orthoses. Significant differences were identified regarding the presence of problems associated with the use of both orthoses. Discomfort was reported as the main reason for unwillingness to use night orthoses, whereas restriction of movement and discomfort were identified as the reasons for unwillingness to use daytime orthoses. While the regularity and duration of night and daytime orthosis use were found to be similar, an increase in parental education level was associated with increased knowledge regarding rehabilitation and CP. The importance of children's adaptation to orthoses and the need for enhanced parental education were emphasized (11,12).

Parents of children with CP bear a considerable burden in terms of orthosis use and rehabilitation follow-up. It has been observed that parents' quality of life and sociocultural characteristics may positively or negatively affect their children's treatment processes. Therefore, it is crucial that parents receive support from healthcare professionals or other family members at home (13). In the present study, parents with lower education levels were also found to have lower monthly incomes. Due to financial difficulties, some families were observed to use the same AFO for extended periods, which resulted in unmet expectations regarding orthosis use.

In our study, night orthoses were used more frequently than daytime orthoses. Accordingly, a difference was observed between the usage durations of night and walking orthoses. The literature indicates that further studies are needed to improve orthosis use and compliance (14,15). In a study conducted with children with CP, the effects of AFO usage duration were investigated. While CP subtype influenced the duration of walking AFO use, it had no effect on the duration of night AFO use. Additionally, parental knowledge regarding rehabilitation was found not to affect the usage duration of either night or walking orthoses. Other factors influencing daily walking orthosis use included the type of CP diagnosis, children's Gross Motor Function Classification System (GMFCS) levels, and families' levels of rehabilitation knowledge (9).

In a study investigating whether orthosis usage duration was effective for treatment in children with CP, questionnaires administered to parents compared orthosis usage data and recovery status of eight children over a one-year period. Significant differences were identified between orthosis usage durations recorded by sensors and those reported by parents. Consequently, it was suggested that parental reports should be considered as maximum estimates. The study emphasized the importance of using different methods to measure orthosis usage duration more accurately and highlighted the need for careful and regular orthosis use, which is a critical factor in children's recovery (16).

In a study conducted on children with CP who experienced sleep disturbances associated with night orthosis use, parental competence and experience levels were compared. Research conducted on 82 children aged between 10 months and 9 years found no significant difference between children who used night orthoses and those who did not; however, a positive association was identified between parents' adequate involvement and interest in orthoses and the absence of sleep-related problems. The study concluded that parents who were consistent in treatment experienced a lower caregiving burden and that enhancing parents' sense of competence in orthosis use and treatment processes could further improve outcomes (9).

In the present study, the primary reasons reported for irregular orthosis use by children included sweating, pain, and children's unwillingness to wear the orthosis. Identifying problems encountered during orthosis use and determining their underlying causes are important for guiding both physiotherapists and parents. When the reasons for irregular orthosis use were examined in the literature, irritation, children's unwillingness, and cosmetic inadequacy of orthoses were reported as the main factors (17). In another study, commonly encountered problems were identified as heel lift-off, excessive flexion at the knees and hips, and excessive lumbar lordosis of the trunk (18). In a qualitative study conducted with parents of children with CP using dynamic AFOs, orthosis effectiveness was evaluated in children aged between 4 and 18 years. In this study involving 15 parents, participants reported that improvements in physiological conditions, functional activities, and psychosocial status were complementary variables contributing to treatment compliance and outcomes in children using orthoses (14).

In the present study, parental inaction or attempts to resolve orthosis-related problems independently were observed in a subset of participants. Although these behaviors may potentially influence children's treatment processes, the available data do not allow for a direct conclusion regarding their impact on treatment outcomes. Nevertheless, these findings highlight the importance of providing parents with more comprehensive and structured information regarding orthosis use, emphasizing the need for close communication between families, physiotherapists, and other healthcare professionals.

Although the present study did not directly assess parental psychological well-being, previous research has shown that having a child with CP may negatively affect parents' psychological status and overall family quality of life. For example, studies have reported associations between the severity of a child's condition and maternal psychological well-being, which may indirectly influence families' experiences with rehabilitation processes. In this context, improvements in children's rehabilitation outcomes may be associated with positive psychosocial effects on families; however, this relationship should be interpreted cautiously, as it was not directly examined in the current study (19).

In the present study, parents' levels of knowledge regarding orthoses were found to be moderate. We believe that implementing interventions aimed at increasing parental knowledge would enhance the efficiency of treatment processes. In a study with similar findings, a significant difference was identified between parents' education levels and their knowledge about CP. Similarly, a significant relationship was observed between parental education levels and understanding the reasons for orthosis prescription (12).

In another study, parents were asked the question, "What do you think is the main problem with your child's orthosis use?" and the reasons for non-use were investigated. Based on the numerical data derived from parental responses, it was revealed that children with CP were unwilling to use AFOs because the orthosis restricted movement. The rigidity of the material used in AFO construction was suggested as the underlying reason for this issue (12). It is considered necessary to develop structured measurement tools in order to obtain more objective data regarding AFO use and compliance processes in children with CP.

In a study conducted by Dilek et al., it was emphasized that identifying factors affecting orthosis usage duration in children with CP—where orthosis use is highly prevalent—is important for guiding future research. Since treatment adherence is a subjective concept that is difficult to evaluate, the study highlighted the need for more objective investigations into factors influencing orthosis use. Furthermore, it was concluded that more comprehensive studies are needed using questionnaires with established validity and reliability and appropriate cultural adaptation to assess orthosis compliance in CP (10). Another study in the literature has also addressed the evidence regarding orthotic/assistive device satisfaction in chronically disabled individuals (20).

The limitations of the present study include the fact that the majority of participating caregivers were mothers, although fathers and siblings also assumed caregiving roles for some children. Considering that mothers typically bear the greatest caregiving burden, not exclusively selecting mothers as caregivers at the outset of the study may be considered a limitation. CP subtype and GMFCS level were not assessed. This is acknowledged as a major limitation of the study, as the absence of CP-specific motor function measures limits the clinical interpretation and comparability of the findings.

Based on the findings of the present study, it was observed that parents' knowledge regarding the CP rehabilitation process and orthosis use was insufficient. Increasing knowledge levels and improving family education in this regard is a shared responsibility of all professionals involved in the rehabilitation team. However, the role of physiotherapists—who play a central role in the rehabilitation of children with CP—is particularly critical. We believe that sharing the results of this study with physiotherapists and special education centers throughout the province of Şanlıurfa will raise awareness and facilitate the initiation of future studies.

CONCLUSION

This study evaluated patterns of ankle–foot orthosis (AFO) use, parental knowledge, and problem-management behaviors among families of children with cerebral palsy in Şanlıurfa. The findings showed that walking AFOs were the most frequently used orthosis type, while night orthoses were used for a significantly longer daily duration. Although the majority of children used their orthoses regularly, more than one-quarter did not, mainly due to discomfort, pain, sweating, skin problems, and difficulties with acceptance and adaptation. When problems occurred, most parents preferred to take the orthosis directly to the manufacturing center, whereas consultation with physiotherapists was rarely reported.

In addition, parental knowledge regarding cerebral palsy and orthosis use was generally limited. In particular, parents reported low perceived effectiveness of AFOs in relation to context-specific pain-related outcomes, compared with other expected benefits such as balance support, deformity prevention, and control of unwanted movements.

Based on these findings, improving structured parental education and strengthening communication between families, physiotherapists, and orthosis providers appear essential. Clear information regarding the purpose of AFO use, realistic expectations, potential sources of discomfort, and appropriate problem-solving pathways may support better adaptation to orthosis use. Future studies incorporating detailed clinical characteristics and longitudinal follow-up are warranted to further clarify factors influencing parental perceptions and orthosis adherence.

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Case Report

FUNCTIONAL RECOVERY FOLLOWING ONE-YEAR REHABILITATION IN A CHILD WITH POST-TRAUMATIC CERVICAL INSTABILITY: A CASE REPORT

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Keywords

Exercise therapy,
Instability,
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ABSTRACT

Purpose: Post-traumatic cervical instability may be associated with persistent functional impairments even after radiological healing has been achieved. Post-traumatic cervical instability may affect movement control, postural regulation, and sensorimotor integration, potentially leading to limitations in head-eye coordination and daily functional activities. Although rigid immobilization and cervical traction are commonly applied during the acute management phase, clinical reports describing rehabilitation approaches targeting sensorimotor recovery following orthotic treatment in pediatric populations remain limited.

Methods: This case report describes a seven-year-old female patient with post-traumatic cervical instability managed conservatively. Orthotic management included full-time cervical traction for approximately two months, followed by use of a Philadelphia collar for approximately two and a half months. Over a one-year period, the patient participated in a structured rehabilitation program emphasizing active postural correction, task-oriented exercises, and cervical stabilization. Due to persistent deficits in head-eye coordination during dynamic activities, an additional eight-week proprioception-focused target-based exercise program was implemented.

Results: Cervical and trunk active range of motion, as well as cervical joint position sense, were assessed before and after the rehabilitation period. Following the intervention, cervical range of motion increased in most movement directions, whereas trunk range of motion demonstrated minimal change. Cervical joint position error values decreased in most directions after completion of the exercise program.

Conclusion: This case describes measurable improvements in cervical mobility and proprioceptive performance following a comprehensive rehabilitation program. The findings emphasize the importance of functional and sensorimotor assessments in monitoring recovery and guiding rehabilitation planning in pediatric patients with post-traumatic cervical instability, alongside conventional imaging findings.

INTRODUCTION

Cervical spine injuries in the pediatric population may result in complex clinical presentations, including post-traumatic loss of stability and impairments in sensorimotor control. Although cervical spine injuries are relatively rare in children, trauma-related

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pathologies such as fractures, subluxations, and ligamentous injuries may occur and can lead to long-term functional impairments (1). In addition, anatomical characteristics of the pediatric cervical spine—including ligamentous laxity, the relative absence of cervical lordosis, and an immature musculoskeletal system—are recognized factors that increase the risk of post-traumatic instability (2).

Traumatic cervical instability refers to a loss of normal segmental control of the cervical spine following injury, resulting in abnormal motion patterns and compromised mechanical support. In pediatric patients, such instability may manifest as altered cervical alignment, reduced postural control, and limitations in functional movement (2). These impairments may interfere with activities requiring head control, visual orientation, and coordinated upper extremity use, thereby affecting daily activities and participation. While structural healing of osseous injuries may be achieved, functional consequences related to movement control and stability can persist beyond the acute phase (3, 4). Therefore, management should not be limited to fracture healing alone but should also address musculoskeletal and sensorimotor aspects of recovery.

External cervical orthoses are commonly used to provide temporary stabilization by limiting cervical motion in patients with cervical instability (5, 6). Depending on the required level of motion control, a range of orthotic designs may be utilized, including soft or rigid cervical collars, such as the Philadelphia, Aspen, or Miami J collars, as well as more restrictive cervicothoracic systems like the Minerva orthosis or Sternal Occipital Mandibular Immobilizer (SOMI) (6). In cases requiring maximal immobilization, particularly in the presence of significant or upper cervical instability, halo-type immobilization may be considered (6, 7). In pediatric patients, custom-made cervical orthoses are frequently used to accommodate anatomical characteristics and growth-related considerations (7). However, evidence suggests that standard cervical collars alone may be insufficient to adequately immobilize an unstable cervical spine, underscoring the need for careful orthosis selection, close monitoring, and integration with comprehensive clinical management (6).

In children, prolonged immobilization, traction, or external cervical support may influence neuromuscular control and sensory feedback mechanisms, which are known to contribute to cervical stability and postural regulation (8). From the perspective of restoring cervical stability and refined movement control, management should not be limited to fracture healing alone but should also address musculoskeletal (including range of motion and muscle strength) and sensorimotor recovery (including postural control, neuromuscular coordination and proprioceptive sense). This broader approach includes components related to movement capacity and stabilization, as well as neuromuscular mechanisms that contribute to cervical and postural control, as described in models of clinical spinal instability that emphasize the role of active and neural subsystems beyond passive structural integrity (4, 9).

When the cervical region is affected following trauma, altered cervical proprioceptive input may disrupt cervico-ocular and vestibulo-ocular reflexes, leading to impaired gaze stability and reduced coordination of head and eye movements (10, 11). If these impairments are not adequately addressed through rehabilitation, symptom-related anxiety and avoidance of movement or daily activities may develop, potentially limiting functional participation (12).

Nevertheless, clinical reports specifically addressing sensorimotor rehabilitation following orthotic management—particularly those focusing on postural control, stabilization, and proprioceptive function—remain limited in the pediatric literature. Therefore, the aim of this case report is to describe a comprehensive evaluation and rehabilitation-based conservative treatment approach in a pediatric patient with post-traumatic cervical instability, with particular emphasis on functional recovery beyond radiological findings.

METHODS

Case History

A seven-year-old female patient sustained a clavicle fracture as a result of a fall at school. No medical intervention was administered immediately following the injury. Two days post-injury, the patient developed cervical deviation accompanied by mandibular protraction. Approximately three weeks after the injury, radiographic and magnetic resonance imaging evaluations confirmed radiological union of the clavicle fracture; however, abnormal cervical alignment persisted.

On clinical examination, the patient presented with a deviated head posture characterized by right lateral flexion and left rotation. She also demonstrated difficulty maintaining a corrected head position.

Interventions

The patient was initially assessed by an orthopedic surgeon and underwent full-time cervical traction therapy for one month during hospitalization (Figure 1), followed by an additional three weeks of home-based traction after discharge (Figure 2). Before being referred to our rehabilitation unit, this traction protocol was used as part of the initial orthopedic management. Throughout this seven-week period, pain-free traction was maintained on a full-time basis, with the traction load progressively increased according to a structured protocol. Traction was initiated with a load of 2 kg and subsequently increased by 2 kg each week until reaching a target load corresponding to approximately half of the patient's body weight (14 kg). In parallel, the daily duration of weighted traction was gradually increased, beginning at 10 minutes per day and progressing to a maximum of 30 minutes per day by the end of the protocol. The traction load was gradually increased under medical supervision and was well tolerated; no neurological, temporomandibular, or other negative effects were noted during the traction period, according to the medical records and caregiver reports.

Figure 1. Cervical Traction Therapy for One Month During Hospitalization

Figure 2. Home-Based Cervical Traction After Hospital Discharge

Following completion of traction therapy, a custom-made Philadelphia-type cervical orthosis (Figure 3), permitting controlled cervical rotation was prescribed and used for approximately two and a half months. During the first month, the orthosis was worn for 23 hours per day and removed for one hour daily for rest. In the second month, a structured weaning protocol was implemented, with daytime wear progressively reduced by three additional hours each week. During the final two weeks, the orthosis was worn only at night before being fully discontinued. Throughout this treatment period, a concurrent exercise program was also implemented.

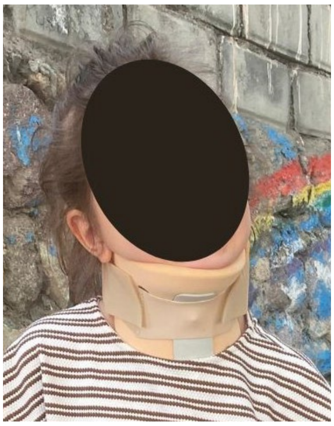

Figure 3. A Custom-Made Philadelphia-Type Cervical Orthosis Used During the Rehabilitation Period

Assessment Protocol

Outcome assessments were performed by an examiner who was not involved in the administration of the exercise program. The patient's medical history was reviewed, and radiographic and magnetic resonance imaging findings were documented. The findings were consistent with atlantoaxial joint subluxation and counterclockwise rotation of the C2 vertebral body.

Cervical active range of motion (AROM) was assessed using the GYKO inertial measurement unit (IMU) system (Microgate, Bolzano, Italy) (13) at three time points: at the initiation of exercise program (approximately 2 months post-injury), immediately prior to the commencement of the proprioceptive exercise program (approximately 10 months post-injury), and following completion of the proprioceptive intervention. Cervical flexion, extension, right and left lateral flexion, and right and left rotation ranges were recorded.

At the beginning of the proprioceptive exercise program, cervical joint position sense was assessed using an active head repositioning test (Figure 4). Cervical angular displacement was recorded using the GYKO IMU system, which was securely positioned on the participant's head according to the manufacturer's guidelines. Participant were guided to predefined target positions of 30° cervical flexion, 30° cervical extension, 30° cervical lateral flexion (right and left), and 30° cervical rotation (right and left). After reaching each target position, participant returned to the neutral starting position and were then instructed to actively reproduce the target angle with their eyes closed. The angular difference between the target position and reproduced position was calculated as the absolute reposition error (°). The selection of a 30° target angle across all movement planes was based on previously established cervical joint position sense assessment protocols reported in the literature (14-17). JPE is commonly reported as angular error and is considered a useful indicator of cervical proprioceptive dysfunction (16). Although precise, age-specific normative cutoff values have not been established for pediatric populations, reductions in joint position error are generally interpreted as clinically meaningful improvements in cervical proprioceptive and sensorimotor control (16, 17). Proprioceptive assessments were performed at the onset of the proprioceptive exercise program and repeated upon completion of the 8-week intervention period.

Figure 4. Active Head Repositioning Test Setup for Cervical Joint Position Sense Assessment Using using an inertial measurement unit (IMU) (A. Inertial Position of Neck B. Flexion of Neck)

Exercise Program

Active Postural Correction and Task-Oriented Exercises

Concurrently with the initiation of Philadelphia-type cervical orthosis use, the patient began a structured exercise program based on active self-correction and task-oriented principles. Initially, the patient was instructed to achieve a corrected head and trunk posture. Subsequently, stabilization of the corrected alignment was practiced during a variety of functional tasks. The exercise program was designed and implemented in accordance with the Scientific Exercise Approach to Scoliosis (SEAS) methodology (18). SEAS was initially developed for the treatment of spinal deformities in AIS, but its fundamental principles are not specific to any particular condition. SEAS emphasizes active self-correction, task- and goal-based motor control, and the integration of postural regulation into functional activities (18). In this case, the selected SEAS principles have been adapted to address cervical instability by focusing on active cervical stabilization, sensorimotor integration, and head-trunk coordination rather than correcting spinal alignment. This conceptual adaptation ensured that the rehabilitation program prioritized neuromuscular control and functional movement strategies in the context of pediatric cervical instability, without implying the direct transfer of scoliosis-specific treatment protocols.

The rehabilitation program was conducted over a 10-month period. Supervised clinical sessions lasting 45 minutes were scheduled once weekly during the first two months, biweekly during the subsequent three months, and once monthly during the final five months. On non-clinic days, the patient continued a 45-minute home-based exercise program. Each rehabilitation session consisted of 6–7 different exercises and included a variety of tasks tailored to the patient's individual needs, targeting cervical and trunk stability, mobility, head-eye coordination, postural control, and functional integration.

At the end of the 10-month exercise program, persistent deficits in head-eye coordination during dynamic activities were identified. Consequently, the patient was additionally enrolled in a proprioception-focused exercise program for a further two-month period.

Proprioceptive Exercise

Proprioceptive exercise was delivered using target-based exercises with the AOS PropPoint device with a laser apparatus, three days per week (19, 20). The program consisted of one supervised face-to-face session of approximately 45 minutes conducted in the clinic and two home-based sessions of approximately 30 minutes each. Exercise involved tracking a target map using head and trunk movements during various tasks, including exercises integrating upper extremity movements (Figure 5).

Figure 5. Target-Based Proprioceptive Exercise Tasks Performed Using a Laser-Guided Visual System

The exercise protocol was structured around goal-directed movements, joint position reproduction tasks, and controlled movement execution. The Target Platform system provided spatial reference and visual feedback during task performance. Exercises were performed under both eyes-open and eyes-closed conditions to progressively reduce visual reliance and enhance proprioceptive input. To further challenge sensorimotor control, tasks were executed on different surfaces, at varying heights, and across sitting, standing, and dynamic postural conditions.

Exercise content focused on head position control, controlled cervical flexion–extension and rotation movements, and maintenance of static head positions aligned with predefined targets. Task difficulty was progressively increased over the eight-week intervention period by modifying visual input, narrowing the base of support, increasing movement amplitude, and enhancing task complexity.

No adverse events were reported during the intervention, and the patient completed the program as planned.

RESULTS

Following completion of the one-year exercise program, changes were observed in cervical and trunk active range of motion. After the initial 10-month active postural correction and task-oriented exercise program, cervical active range of motion increased in movement across all planes (Table 1). Improvements included increases of 10° in flexion, 6° in extension, 21° in right rotation, 30° in left rotation, 19° in right lateral flexion, and 11° in left lateral flexion.

Following the subsequent two-month proprioceptive exercise program, additional increases in cervical range of motion were observed. Cervical flexion increased by 6°, extension by 10°, right rotation by 14°, left rotation by 3°, and left lateral flexion by 13°, while right lateral flexion remained unchanged (Table 1).

Trunk active range of motion showed minimal changes throughout the intervention period. Small variations were observed, including a 1° increase in trunk flexion, a 1° decrease in extension, a 2° decrease in right rotation, a 1° increase in left rotation, a 12° increase in right lateral flexion, and a 3° increase in left lateral flexion (Table 1).

Table 1. Range of Motion Before and After an 8-Week Proprioceptive Exercise Program

	Range of Motion		
Motion	**At the initiation of Task-Oriented Exercise Program** (2 months post-injury)	**Before Proprioceptive Exercise Program** (10 months post-injury)	**After Proprioceptive Exercise Program** (12 months post-injury)
Cervical (°)			
Flexion	26	36	42
Extension	28	34	44
Right Rotation	18	39	53
Left Rotation	14	44	47
Right Lateral Flexion	23	42	42
Left Lateral Flexion	19	30	43
Trunk (°)			
Flexion		89	90
Extension		22	21
Right Rotation	n/a	35	33
Left Rotation		29	30
Right Lateral Flexion		34	46
Left Lateral Flexion		41	44

Values represent single-subject measurements. Absolute change (Δ) indicates the numerical difference between pre- and post-intervention assessments. n/a: not available

Cervical joint position error values decreased after completion of the proprioceptive exercise program in most movement directions. Reductions were observed in cervical flexion (from 8° to 4°), extension (from 14° to 4°), left rotation (from 14° to 6°), right lateral flexion (from 28° to 22°), and left lateral flexion (from 12° to 10°). No change was observed in right rotation joint position error, which remained at 4° before and after the intervention (Table 2).

Table 2. Joint Position Error Before and After an 8-Week Proprioceptive Exercise Program

	Joint Position Error at 30°		
Motion	**Before Proprioceptive Exercise Program** (10 months post-injury)	**After Proprioceptive Exercise Program** (12 months post-injury)	**Change (Δ)**
Cervical (°)			
Flexion	8	4	−4
Extension	14	4	−10
Right Rotation	4	4	0
Left Rotation	14	6	−8
Right Lateral Flexion	28	22	−6
Left Lateral Flexion	12	10	−2

Joint position error values represent absolute angular error (°) during active head repositioning tasks at a target angle of 30°.

At the end of the treatment period, the patient achieved a neutral, vertically aligned head posture and was able to maintain an upright head position while looking straight ahead. No adverse events or symptom exacerbations were reported during the intervention period, and the patient completed the program as planned.

DISCUSSION

This case report describes the functional recovery of a child with post-traumatic cervical instability following a conservative treatment strategy consisting of cervical traction, orthotic management, and a structured rehabilitation program (SEAS and target-based exercises), with observed improvements in head posture, cervical mobility, and proprioceptive performance over the follow-up period.

In the present case, cervical range of motion demonstrated a gradual and plane-specific improvement over the follow-up period. Reduced cervical mobility is commonly reported following cervical trauma and prolonged immobilization (21). Notably, cervical range of motion increased across all movement planes following the initial 10-month exercise program emphasizing active postural correction and task-oriented exercises, with further, albeit smaller, gains observed after the subsequent proprioceptive training phase. These improvements occurred in the absence of aggressive mobilization or manual stretching techniques. This suggests that the observed changes likely reflect a progressive restoration of neuromuscular control and movement confidence rather than abrupt structural alterations.

Results from previous work suggest that improvements in cervical range of motion may be achieved through rehabilitation programs that focus on restoring sensorimotor control and segmental stability, rather than through passive mobilization alone. In this context, interventions that include head repositioning activities and carefully controlled movement tasks have been linked to concurrent improvements in cervical joint position sense and active cervical mobility in individuals with cervical dysfunction (3, 22). Comparable findings have also been reported in trauma-related neck conditions, such as whiplash-associated disorders, where exercise programs targeting deep cervical muscle activation and stabilization were associated with increased cervical mobility together with better movement control and functional performance (23).

In addition to improvements in cervical mobility, proprioceptive performance, assessed by cervical joint position sense measures, also improved over time. Cervical joint position error is widely used as a clinical indicator of proprioceptive accuracy in individuals with cervical dysfunction, and increased repositioning error has been reported following cervical injury (3, 14). In the present case, the observed reduction in repositioning error during follow-up suggests enhanced accuracy in reproducing cervical positions. As underlying neuromuscular or sensory mechanisms were not directly examined, these findings are interpreted descriptively as improvements in proprioceptive performance rather than evidence of specific physiological adaptations.

The additional improvements observed following the proprioceptive intervention, particularly in flexion, extension, and rotational movements, may indicate enhanced sensorimotor integration and improved precision of cervical movement. In contrast, trunk range of motion showed minimal change throughout the intervention period, supporting the notion that the observed cervical improvements were region-specific and related to targeted rehabilitation rather than generalized mobility gains. Clinical literature suggests that recovery processes following cervical instability extend beyond the restoration of joint excursion and also involves improvements in movement accuracy and neuromuscular control. In this context, reliance of radiological findings alone may be insufficient to identify residual functional deficits, particularly in cases characterized by subtle or low-grade instability (21). Functionally, the patient initially experienced difficulty maintaining head-eye coordination during sustained visual tasks such as reading and classroom activities that required prolonged visual attention, as well as during visual scanning while walking. After an 8-week proprioceptive exercise program, both the patient and caregiver reported improved tolerance for these tasks and greater fluidity in head-eye coordination during daily activities.

The restoration of a neutral, vertically aligned head posture with the ability to maintain forward gaze represents a clinically meaningful outcome in the context of cervical instability (21). This postural improvement occurred alongside gradual increases in cervical range of motion and reductions in joint position error, suggesting concurrent enhancements in mobility, movement control, and proprioceptive accuracy (3). Together, these findings suggest improved neuromuscular coordination of the head–neck complex, which is commonly compromised following cervical trauma and prolonged immobilization. The minimal changes observed in trunk range of motion further support the interpretation that these improvements were region-specific (4) and attributable to targeted cervical rehabilitation rather than generalized mobility gains.

In the present case, rehabilitation was implemented in a gradual and closely monitored manner, emphasizing the restoration of controlled cervical movement. This approach aligns with conservative strategies reported in the literature, in which progression is guided by symptom response and aggressive mobilization is avoided when cervical instability is a concern. Within this framework, the observed improvements over the one-year follow-up period are best interpreted as functional recovery outcomes reflecting enhanced movement stability and tolerance to activities of daily living, rather than as evidence of specific mechanistic adaptations (9, 21).

CONCLUSION

This case report describes the conservative rehabilitation course of a child with post-traumatic cervical instability. Over the follow-up period, measurable improvements were observed in cervical mobility and in the accuracy of cervical joint position sense, reflecting a functional recovery beyond radiological healing alone. Although the findings derived from a single case do not allow causal inferences, they underscore the clinical relevance of incorporating functional and sensorimotor assessments alongside imaging findings when monitoring recovery and planning rehabilitation in pediatric patients with cervical trauma. Future studies are warranted to further explore the role of structured rehabilitation and proprioceptive training in this population.

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Informed Consent: Written informed consent was obtained from the patient’s legal guardian for participation in the study and for the publication of clinical data and images.

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