Case Report

The Efficacy of Ortho-Prosthesis and Knee Ankle Foot Orthosis on Functional Gait Activities in Pediatric Congenital Limb Deficiency: A case report

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ABSTRACT

Objectives: This study aimed to demonstrate the efficacy of ortho-prosthesis and knee-ankle foot orthosis (KAFO) in improving functional gait activities in children with congenital limb deficiencies.

Study design: A case report.

Setting: Sirindhorn School of Prosthetics and Orthotics, Faculty of Medicine Siriraj Hospital, Mahidol University.

Subjects: The study presents the case of a 10-year-old child with a left congenital femoral deficiency with fibular hemimelia and right tibial hemimelia.

Methods: A pediatric orthopedist provided surgical treatment, and a prosthetist and orthotist prescribed the design, choosing the appropriate KAFO for the right side and ortho-prosthesis for the left side. Outcome measurements were recorded using the Four Square Step Test (FSST), Time Up and Go (TUG) Test, and the 10-Meter Walk Test after using the devices for two and five months.

Results: The results of FSST and TUG showed improvement after five months of training, with 19.69% and 34.25% less time required, respectively. The parameters of the 10-Meter Walk Test also improved after five months of training.

Conclusions: Appropriate fitting of different devices and training using those devices can help improve balance and functional gait activities in children with congenital limb deficiencies.

Keywords: tibia hemimelia, knee ankle foot orthosis, ortho-prosthesis, congenital femoral deficiency

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Introduction

Congenital limb deficiency is a partial or complete absence of a limb due to limb formation failure during pregnancy. The etiology of congenital limb deficiencies is unknown; lower limb deficiencies are generally less common than upper limb deficiencies.[1] Surgical amputation is necessary in only 19% of cases of congenital limb deficiency.[2] Children with limb deficiencies may require a multidisciplinary team to help them manage their condition and to achieve their maximal functional capacity. The goals of surgery in cases of congenital limb deficiency are to remove the bony overgrowth or to adjust the residual limb to facilitate proper prosthesis fitting.[3] Prostheses and orthoses can help these children achieve independence in activities of daily living. The prosthesis and orthosis prescription and fitting process considers several factors, including the child's cognitive maturity and physical ability.

The fitting typically begins for children with lower limb deficiencies between nine to sixteen months of age. Children with congenital limb deficiencies often experience unstable gait patterns due to heavy and locked joints of the knee and ankle. Providing appropriate training during the initial phase of prosthesis fitting can help reduce gait deviations and improve gait stability.[4] However, previous studies have rarely addressed congenital limb deficiencies and the effectiveness of ortho-prosthesis and knee-ankle foot orthosis in improving functional gait activities in those cases. There is also a need to investigate the impact of these devices on outcome measures and to determine the necessity for periodic replacement of prostheses and orthoses as the child develops. This study aimed to demonstrate the efficacy of ortho-prosthesis and knee-ankle foot orthosis (KAFO) in improving functional gait in cases of congenital limb deficiencies.

Case presentation

The subject was a 10-year-old male subject (weight: 37.4 kg, height: 124 cm) with a left congenital femoral deficiency and fibular hemimelia (Paley 3c) and right tibial hemimelia (Jones type I, Paley 5b).[5] Congenital femoral deficiency presented as congenital short femur with fibular hemimelia (Paley 3C).[6] The neck of the femur had retroversion, genu varum, and hypoplasia of the lateral condyle, causing knee instability in the anteroposterior plane and muscle and vascular pathoanatomy. Physical characteristics included leg length

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discrepancy, hip flexion contracture, hip rotation instability, knee instability, and fixed equinovarus. He received limb lengthening to extend the femur and shortening osteotomy to realign the distal tibia (Figure 1).

Tibial hemimelia with Jones type I presented as a total absence of the tibia and hypoplastic distal femoral epiphysis. Paley 5b presented as the absolute absence of the tibia and patella. Physical characteristics presented included genu valgum, complete toe development, and fixed equinovarus. He initially received orthopedic treatment with Brown's procedure (fibular centralization) for tibial hemimelia. The first correction of knee flexion contracture used a k-wire to stop partial bone growth after the fibula had been moved to the central part of the knee and the knee joint began to straighten, followed by a second operation for fixation of the fibular head with the femur, creation of ligament and muscle by separating the peroneal nerve from the fibular bone and bisecting the biceps tendon to create a lateral collateral ligament and, in place of the quadriceps, connecting the semitendinosus tendon, iliotibial band, tensor fascia latae, and adductor magnus to the muscle of the femur so all the transfer muscle would bring the fibular bone to the center and using k-wire at the fibula and distal femur for the prevention of fibular slip. The next operation was knee extension using a circular frame and k-wire. The k-wire was removed after six months, but KAFO and the physical therapy approach were continued.

The patient was referred to the prosthetics and orthotics clinic after a surgical assessment procedure and prescription of the appropriate ortho-prosthesis (left) and KAFO (right). The assessment of the patient found that the left hip showed external rotation and flexion contracture, along with a knee flexion contracture of approximately 10 degrees and equinovarus of the foot. On the right side, there was also hip external rotation and flexion contracture, along with knee flexion and foot plantarflexion (Fig. 2). Range of motion was limited, and manual muscle testing yielded a grade of 3 with a positive Thomas Test. The subject always used an ortho-prosthesis and KAFO to perform activities by himself at school and outside the home, but he performed daily activities at home without any device. He had used several ortho-prostheses and KAFOs after the surgical procedures to support growth development.

Ortho-prosthesis and KAFO design and techniques

The child's lower limb devices comprised an ortho-prosthesis for the left and KAFO for the right. Both devices allowed full weight bearing and were designed to provide stability and support while walking. A prosthetist and an orthotist took a cast of the right side at the hip level to fabricate a KAFO to reduce the chances of ankle and knee contracture. The casting process for the KAFO involved a two-step approach, beginning with a partial weight casting of the patient's right leg while seated with the hip and knee flexed at 90 degrees and the ankle corrected for any deformities. Plaster of Paris was applied using a slab technique from the calf to the plantar surface, followed by circumferential wrapping from the shank to the foot to capture the shape of the leg. The plaster was then allowed to harden, after which a full weight-bearing casting was made with the patient standing to ensure stability and proper alignment. The heel compensation was set in the fabrication process by drawing a reference line perpendicular to the floor in both the coronal and sagittal planes.

Special attention was paid to sensitive and prominent areas, with modifications made to the plaster to build up areas as needed for comfort and fit. Flaring techniques were used at

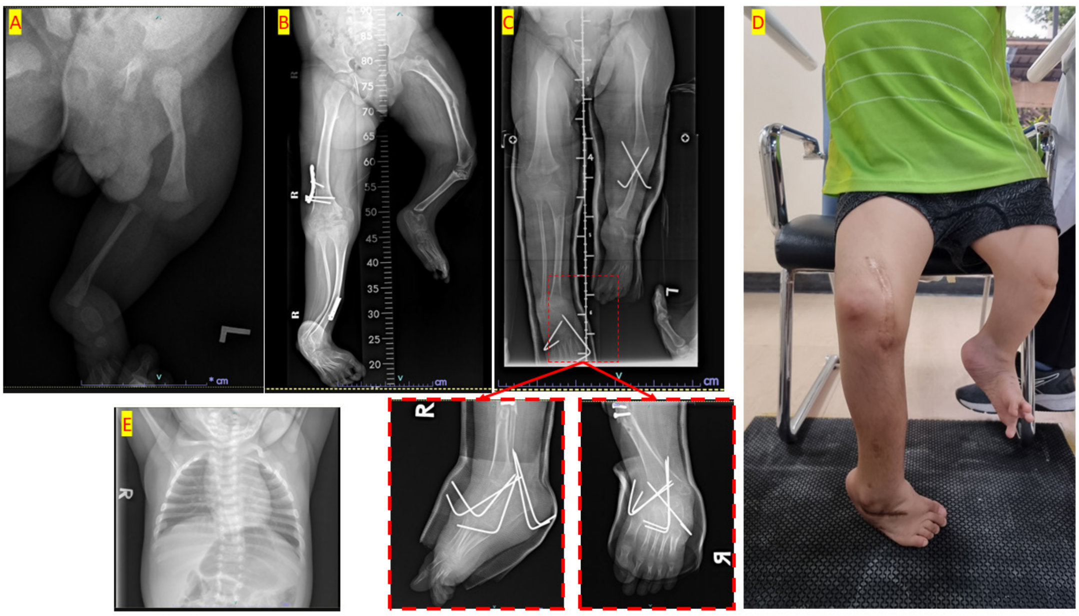

Figure 1. Radiography of left congenital femoral deficiency with fibular hemimelia and right tibial hemimelia. A: malaligned fibula and femur bones resulting from maldevelopment of the lower limb; B: internal fixation of the right femur de-rotation with extension osteotomy plate, right tibial de-rotation with a tubular 1/3 plate; C: internal fixation to correct the foot in both the sagittal and coronal plane; D: standing without supportive device; E: effect of anomalies on the spine.

Figure 2. A: Sagittal plane view of the right leg with full extension; B: Top view in the supine position

Figure 3. Fitting with: A: right side knee-ankle foot orthosis and B: left side ortho-prosthesis

the device's opening to facilitate donning and doffing and to prevent the edge of the device from pressing against the patient's skin. The fabrication used a 5 mm thick sheet of polypropylene plastic with a foam liner to minimize skin friction and a stainless-steel upright. First, a positive cast was created, then thermoformed using a plastic material along the anterior seamline. The upright was then bent along the plastic shell in both the upper and lower parts.

The next step involved cutting and fabricating the heel compensation part according to the patient's alignment. Biomechanical techniques were employed in the fitting and delivery process using a 3-point pressure system. The trim line was established by positioning the proximal thigh section beneath the gluteal area and 2.5 cm below the perineum area and aligning the greater trochanter neck with a posterior thigh shell to provide a counterforce. The distal thigh section was placed above the medial and lateral condyles. The proximal leg section encompassed the anterior knee area, employing a plastic shell instead of a kneecap to deliver the necessary corrective force. The distal leg section was fitted with a posterior shell that offered additional counterforce. The full-length foot section covered the distal first metatarsal head and proximal fifth metatarsal head to manage varus deformity. Straps were attached at the thigh part 45 degrees from the ankle and around the metatarsal head. An anti-slipper was affixed to the footplate's underside to facilitate walking without shoes. This feature is particularly useful for patients with heel compensation or uneven leg length, as they may require an outsole to achieve a plantigrade foot alignment with the floor. Additionally, it addresses the challenge of finding suitable footwear for these patients. The ortho-prosthesis consisted of a quadrilateral socket, drop lock orthotic knee joint attached using an exoskeletal prosthesis fabricated from acrylic resin and a metal upright bar (Figure 3).

Pediatric orthotic training and outcome measures

The child's training began with introducing him to the ortho-prosthesis and KAFO, followed by an Introduction and Familiarization phase. After he became comfortable with the prosthesis, the static balance training phase began, teaching the child to balance while standing in parallel bars. Following that, Dynamic Balance Training helped the child maintain balance while walking with gradually decreasing support. Gait Training then taught the child to walk with the ortho-prosthesis and KAFO, starting with short steps and progressively increasing stride length. Additionally, the child underwent endurance and strength training to improve walking abilities. Advanced training was then begun to achieve the goal of independent walking and playing with friends, including running, jumping, and sports-specific movements. After giving him the devices, we followed up with the patient at two and five months to recheck the quality of the device and the patient's performance. Each outcome measurement was repeated three times, and the average value was recorded.

The assessment included using a BTS-G Walk sensor to evaluate the patient's functional gait performance with the orthosis and ortho-prosthesis during a 10-Meter Walk Test and the Timed Up and Go Test on a level surface. The Four Square Step Test was also performed without any assistive devices.

Four Square Step Test (FSST)

The Four Square Step Test (FSST) is used to check a subject's dynamic stability and ability to step forward, sideways, and backward over small obstacles. The FSST results after five months showed a 19.69% improvement over the results after two months.

Timed Up and Go (TUG) Test

The time to complete the TUG Test showed the difference between the device's short- and long-term use. The TUG Test showed a reduction of 34.25% after using the devices for five months compared to two months.

10-Meter Walk Test

The 10-Meter Walk Test revealed improvements in several variables after using ortho-prosthesis and KAFO for five months compared to two months. Both the symmetry index and the walking quality index also showed improvement after using the ortho-prosthesis for five months. However, the improvement from using KAFO as measured by the Gait Quality Index for five months compared to two months was found to be minimal.

Results of the Four Square Step Test, Time up and go, and 10-meter walk test with ortho-prosthesis and KAFO after using the devices for two months and five months are shown in Table 1.

Discussion

This case study aims to evaluate the efficacy of ortho-prostheses and KAFO in improving gait stability, reducing gait deviations, and enhancing the overall quality of gait in children with congenital limb deficiencies. The findings suggest that appropriate ortho-prosthesis and KAFO interventions can effectively improve gait stability in children with congenital limb deficiencies, potentially leading to improved mobility and reduced risk of falls. The choice of prosthesis and orthosis design is crucial to enhancing the ability to carry out various activities. The ischial containment socket ortho-prosthesis design effectively redistributes and offloads weight to a two-point load-bearing area at the ischium and the foot heel, reducing excessive pressures on the leg during ambulation. Additionally, the KAFO design, with an anterior shell providing improved leg control by pushing the knee backward during ambulation, reduces the likelihood of developing further contractures. The locked knee joint with KAFO enhances stability by preventing knee collapse while walking.

The incidence of successful adaptation to ortho-prosthesis in children with congenital limb deficiency is greater than in adults with traumatic limb amputation.[7] Individuals with limb loss resulting from accidents or amputations exhibit a higher tendency to experience falls while performing stability tasks that take longer than 24 seconds.[8] Differences in successful adaptation and fall risk may be attributable to variations in the individual's age at onset, the nature of the limb loss, and differences in cognitive abilities between children and adults. The Four Square Step Test (FSST) is a standardized assessment tool that is used to measure dynamic stability and the ability to step over obstacles in different directions. It is often used to assess an individual's risk of falling, balance, and mobility. The current study showed improved FSST performance after five months of using prosthetic devices.

The secondary objective is to describe and propose a systematic, objective assessment process for ortho-prosthesis fitting in children with congenital limb deficiencies. The Time

Table 1. Outcome of the Four Square Step Test, Timed Up and Go Test and 10-Meter Walk Test

Variable mean (SD)	2 months	5 months	Difference
Four Square Step Test (s)	16.51 (0.4)	13.65 (2.39)	2.86
Time Up and Go Test (s)	11.68 (1.71)	9.14 (0.78)	2.54
10-Meter Walk Test			
Walking duration (s)	10.82 (1.32)	11.5 (0.84)	0.68
Walking speed (m/s)	1.21 (0.16)	1.23 (0.12)	0.02
Symmetry index	72.83 (12.48)	82.06 (6.54)	9.23
Walking quality index left	94.91 (4.73)	98.08 (2.46)	3.17
Walking quality index right	92.84 (2.57)	93.96 (4.12)	1.12

s, seconds; m/s, meters/second

Up and Go (TUG) Test is a commonly used assessment tool to assess the risk of falling in people who use prostheses or orthoses. Some researchers have used two different models (Gaussian bell-shaped curve and linear regression line) to classify participants as fallers or non-fallers based on their TUG Test data. Both models have been able to distinguish between fallers and non-fallers significantly. These findings suggest that the TUG Test could help assess the risk of falls in older adults and may be more efficient and precise than other methods currently used.[9] The TUG Test is a good diagnostic tool for differentiating between groups of patients. It can help assess the mobility of children and adolescents, monitoring the effects of physical therapy and surgical procedures.[10] Promising improvement was observed in the current study using the proposed assessment process.

The current study found improvement during the 10-Meter Walk Test. The result exhibited greater improvement with the ortho-prosthesis than with the KAFO. The 10-Meter Walk Test is a commonly used assessment tool in the medical field to evaluate gait patterns and identify specific gait parameters that may be affected by neurological or orthopedic conditions. It is a quick and easy way to measure walking speed, cadence, step length, stride length, and other parameters such as walking symmetry and propulsion. Gait parameters, e.g., stance, swing, and double support times, can vary significantly during fast walking in children aged 5-8. This information serves as a valuable reference point for clinicians and researchers to compare gait patterns of children with abnormalities and evaluate the effectiveness of interventions to improve gait.[11] However, recent research has shown that gait patterns during the 10-Meter Walking Test, which is commonly used in clinical practice, differ from observations of walking at home among individuals with hemiparesis. The main difference is in stride length, with exercises focusing on improving stride length recommended for enhancing walking ability at home. Clinicians should consider the specific gait parameters being measured when assessing and treating gait abnormalities in their patients.[12]

Ortho-prosthesis and KAFO interventions can improve gait outcomes in children with congenital limb deficiencies. From a clinical perspective, the findings of this study have important implications for the selection of treatment for children with congenital limb deficiencies. Specifically, clinicians may consider using a prosthesis or orthosis in conjunction with outcome measures to improve gait and reduce the risk of falls in this population. Additionally, using outcome measures may help clinicians monitor the effectiveness of interventions over time and adjust treatment plans accordingly.

The methods for improving gait outcomes used in this study could lead to increased mobility and reduced risk of falls for children with congenital limb deficiencies. In this case study, the longer walking duration at five months compared to two months highlights some important factors that might influence individual progress and adaptation to ortho-prostheses and KAFO. Initially, i.e., during the first few months, the child may still adjust to the new devices, resulting in slightly slower walking times. Their walking duration should improve as they continue to practice and gain more experience. The improvement in walking duration also reflects the strengthening of muscles employed during walking resulting from consistent use of ortho-prostheses and KAFO. Moreover, the child may gain confidence and experience increased comfort, which can positively impact walking performance as reflected in a smoother and more efficient gait and contribute to longer walking duration.

Conclusions

The present case study provides evidence that ortho-prosthesis and KAFO effectively improve functional gait outcomes in children with congenital limb deficiencies. The interventions using those devices demonstrated positive effects on increasing gait stability, reducing gait deviation, and improving overall gait quality. These outcomes were evident in the improvements in the Four Square Step Test, Time Up and Go Test, and the 10-Meter Walk Test. Using an ortho-prosthesis and KAFO resulted in enhanced functional mobility and gait performance in the children, highlighting the importance of appropriate fitting of the devices and subsequent training using these devices. These findings contribute to a better understanding of the potential benefits of these interventions in improving the quality of life for children with congenital limb deficiencies.

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