A Study on Dynamic Hip Brace with Variable Hip Abduction and Adjustable locking Mechanism in patients with Spastic Diplegic Cerebral Palsy: A Prototype

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Abstract:

Background: Cerebral palsy (CP) is a term used to describe a problem with movement and posture that make certain activities difficult which results from damage to part of the brain. Among the different types of CP, Spastic CP is the most prevalent, accounting for approximately 70% of cases. This is characterized by increased muscle tone in the upper limbs and the lower limbs. Many children with CP exhibit a crouch gait, a movement pattern characterized by excessive flexion of the knee in terminal swing and throughout the stance phase of the gait cycle. If left untreated, this pathological gait pattern increases the cost of locomotion and tends to worsen over time. In this study, a dynamic hip brace was designed which enables controlled hip abduction, aiming at reducing scissoring gait, and facilitating anterior pelvic rotation for improved postural alignment.

Methods: The Dynamic hip brace was fabricated using polypropylene and incorporated an adjustable mechanical joint. The joint components were manufactured using Polylactic acid (PLA) material through a 3D printing process utilizing an ENDER-3 Pro 3D printer.

Results: The prototype dynamic hip brace provides controlled hip abduction at fixed angular intervals and restricts excessive adduction during functional activities. The brace geometry and joint mechanism show the ability to influence pelvic alignment and lower-limb posture, indicating possible benefits for postural control and gait correction.

Conclusions: It is concluded that the proposed dynamic hip brace with variable hip abduction and adjustable locking mechanism provides an innovative solution to children with spastic diplegic CP to overcome the scissoring gait and adductor tightness. Further the study demonstrates the potential of the brace as a supportive aid for improving functional posture and mobility.

***Index Terms*:** Cerebral palsy, Sitting, Functional sitting position, Hip abduction orthosis

I. INTRODUCTION:

Cerebral palsy (CP) is a term used to describe a problem with movement and posture that make certain activities difficult. "Cerebral"- refers to the brain. "Palsy- means weakness or paralysis or lack of muscle control. Therefore, cerebral palsy is a disorder of muscle control which results from damage to part of the brain. The motor disorders of CP are often accompanied by disorders of sensation, perception, cognition, communication, and behavior by epilepsy, and by secondary musculoskeletal problems [1]. It has often been considered the prototype childhood 'neurodisability' (Rosenbaum 2003). It is usually identified as the most common physically disabling condition seen and managed by child health professionals, with a prevalence of 2.0-2.5 per 1000 live births [2].

Global population-based studies indicate a prevalence of CP ranging from approximately 1.5 to 4 per 1000 children. In low- and middle-income countries (LMICs), the prevalence of CP is expected to be higher than in high-income countries, carrying an

increased risk of severe motor impairments, poor nutritional status, and diminished health-related quality of life [3].

Among the different types of CP, spastic CP is the most prevalent, accounting for approximately 70% of cases (Evensen et al., 2023) [4]. The primary lesion site in spastic CP is the pyramidal system, characterized by increased muscle tone in the flexor muscles of the upper limbs, extensor muscles of the lower limbs, and adductor muscles. In later stages, tendon contractures, joint deformities, and muscle atrophy may occur, leading to significant impairment in gross motor function and severely impacting the affected child's daily life. Many children with cerebral palsy walk in a crouch gait, a movement pattern characterized by excessive flexion of the knee in terminal swing and throughout the stance phase of the gait cycle. If left untreated, this pathological gait pattern increases the cost of locomotion (Campbell & Ball, 1978; Waters & Lunsford, 1985; Rose et al., 1990) and tends to worsen over time (Sutherland & Cooper, 1978; Bell et al., 2002), leading to joint pain and degeneration [5].

Children with cerebral palsy (CP) exhibit spasticity, muscle weakness, and immobility, in combination with an inability to deal with the effects of gravity. Thus, these children are at risk of developing muscle windswept hip deformity (WHD). WHD is a postural deformity characterized by one hip in abduction and external rotation, while the opposite hip is in adduction and internal rotation. In children with CP, particularly spastic CP, increased muscle tone, weakness, and imbalance can lead to muscle contractures and joint deformities, including Windswept Deformity. This can cause difficulty with sitting, standing, and rolling over. Individuals with spastic diplegia develop scissoring gait as the most common pattern of walking. This type of CP occurs when motor impairments predominantly affect the legs. Scissoring gait is a distinctive walking pattern where the legs cross over in a scissor-like motion, leading to knees and thighs hitting or crossing during walking. It is caused by high muscle tone (spasticity) in the hip adductors. The hip adductors are the muscles responsible for bringing the thighs together. Because these muscles remain contracted, internal hip rotation occurs and the upper half of the legs cannot be separated while walking.

There are various existing hip abduction orthosis such as Newington Orthosis, Cosa hip abduction orthosis, Resting abduction orthosis, A-frame orthosis, RCAI Hip Abduction Orthosis that are used to prevent adduction and medial hip rotation. However, these hip abduction braces can significantly limit the natural range of hip motion as they are static and do not allow for dynamic movement or adaptation to various activities. Therefore, the aim of this study was to develop a Dynamic Hip Brace with variable hip abduction and adjustable locking mechanism that helps in locking the hip in a desired position of abduction and also maintain the desired external rotation of the thigh.

II. METHODOLOGY:

Flexion and extension are essential movements of the hip joint during walking. Incorporating these functions in individuals with spastic diplegic CP is crucial for improving walking efficiency and overall functional mobility. However, re-establishing these movements requires consideration of several external factors, particularly in the context of current economic constraints. Although significant advancements have been made in orthotic device technology over the years, the high cost and limited availability of custom-fabricated solutions render many modern innovations unaffordable for a large proportion of patients.

The proposed design aims to enhance functional performance while improving accessibility and user compliance, particularly in resource-limited settings.

Material Selection

The following materials were selected for the design and fabrication of dynamic hip brace.

1. Polypropylene Pelvic Section
2. Thigh cuffs
3. 6mm round stainless-steel bar
4. Variable position locking joint (3D Printed)
5. Pelvic Straps

Design concept:

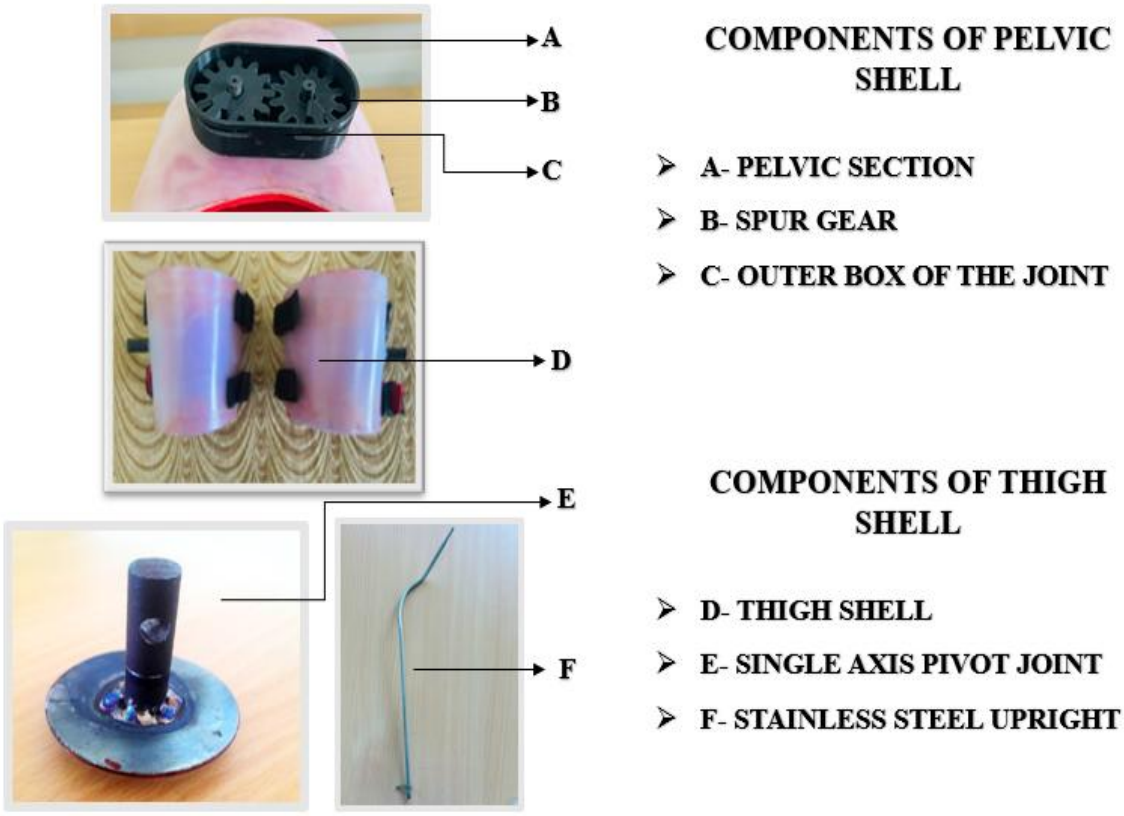
The brace features a polypropylene pelvic section that extends from L2/L3 to distal margin of the sacrum, providing maximum thoracic and pelvic support. Patients with low trunk tone and/ or very limited trunk control strength may benefit from the increased posterior and lateral support. A variable position locking joint with spur gear mechanism was designed which is oriented just proximal to the sacral region of the pelvic section. Two stainless steel uprights were extended from the joint proximally and attached with the thigh shell distally using a free-rotating clamp. The upright is aligned at 123˚abduction with respect to the brace that aids in greater adductor muscle lengthening, more trunk lumbar flexion that assists during gait. The

uprights were placed as close as possible to the greater trochanters without impinging on them when the hips are flexed.

This design promotes locking the hip in abduction at 30˚ intervals and it restricts further adduction once it is locked. Proximally Pelvic straps and distally thigh straps were used to anchor the polypropylene pelvic shell and thigh shells respectively.

Components:

1. Polypropylene Pelvic Section
2. Thigh cuffs
3. 6mm Round Stainless-Steel bar
4. Variable position locking joint (3D Printed)
5. Pelvic straps
6. Thigh straps



MATERIAL ADOPTED FOR 3D PRINTING

The material opted for 3D printing is Poly-lactic acid which has characteristics like tensile strength of 50 megapascals, moderately flexible, the melting point ranges from 130-180 degrees, selectively corrosive to specific materials like carbon / iron and is non-toxic, readily available, and inexpensive.

3D PRINTING MECHANISM:

The joint design process began with manual sketches to define component dimensions, followed by precise measurement analysis. These measurements were translated into a 2D CAD model using GEOMAGIC Design X software. Three-dimensional models of the outer casing and spur-gear components were created separately and assembled digitally.

Upon completion of the CAD model, the design was transferred to ENDER Pro slicing software. The model was fabricated using fused deposition modelling (FDM), in which thermoplastic filament was extruded through a heated nozzle and deposited layer by layer. Support structures were printed simultaneously and removed following fabrication. G-code generation was performed using CREALITY software, and printing was completed using an Ender-3 Pro 3D printer with a total build time of approximately 11 hours and 59 minutes.

Following fabrication, the joint assembly was integrated with the polypropylene pelvic shell and positioned over the sacroiliac joint. The 3D-printed spur gear incorporated a hollow section to accommodate and internally secure the round upright. Distally, the upright was bent to 123° of abduction and attached to the thigh shell. This configuration promoted posterior pelvic rotation and enhanced trunk flexion during gait, while the free-rotating clamp allowed unrestricted hip flexion during sitting.

FIGURE.3 Joint External-Box and Spur Gear Design Made From Software

FIGURE.4 Final Printed Prototype Design From Ender-3 Pro 3d Printer

WORKING PRINCIPLE:

The dynamic hip brace incorporating a variable hip abduction joint to increase hip abduction angulation and to lock the hip at a desired position using a locking screw integrated within the joint. The joint mechanism consists of a spur-gear assembly that enables controlled hip abduction and allows locking at 30° intervals. An internal self-tapering screw restricts anticlockwise rotation of the gear, thereby preventing unwanted adduction and maintaining the selected abduction angle.

As the hips move into flexion during sitting, the uprights guide the femurs into further abduction, creating a stable tripod base that enhances sitting stability and provides sustained stretching of the hip adductor musculature. Improved control of scissoring gait, a more upright posture, and smoother transitions between standing and sitting with minimal external assistance contribute to meaningful functional benefits in ambulatory patients.

The motion pathways of the thigh cuffs are designed to closely replicate physiological femoral kinematics. This is achieved through a combination of pelvic band angulation in the sagittal plane and hip joint assembly orientation in the transverse plane. These design features generate an external rotary influence on the lower limbs, promoting knee extension and facilitating a more erect trunk posture. When the joint reaches its adduction limit, adductor forces are transmitted proximally to assist posterior pelvic rotation, further enhancing postural alignment and gait efficiency. The uprights, distally attached to the thigh shells via a variable-rotation joint, allow controlled hip flexion during sitting and extension during standing, thereby supporting functional postural transitions. However, due to the absence of an automatic locking mechanism, hip abduction angulation requires manual adjustment. Appropriate patient training is therefore essential to ensure safe usage and to maximize the functional benefits of the orthosis.

Overall, this design demonstrates the potential of combining biomechanically informed orthotic principles with additive manufacturing techniques to develop cost-effective, customizable solutions for managing spastic diplegic scissoring gait.

Figure.5: The Prototype of the Developed Dynamic-Hip Brace

III. DISCUSSION:

In pathological conditions such as spastic hemiplegia, diplegia, and quadriplegia, hip abduction orthoses are widely used to promote proper gait and prevent scissoring. These orthoses are biomechanically designed to control abnormal muscle forces, maintain hip abduction, and prevent the development or progression of adduction contractures.

Commercially available devices such as the SWASH (Standing, Walking, and Sitting Hip) orthosis are widely used and have demonstrated positive functional outcomes. Boyd et al. (2001) reported improvements in sitting and standing stability, reduced hip adduction contractures, and better control of scissoring gait in children with spastic diplegic cerebral palsy using the SWASH brace. Despite these benefits, SWASH orthoses have several limitations, including lack of a mechanism to lock the hip at a desired abduction angle, bulky design, increased weight, and high cost. These factors may contribute to increased energy expenditure during ambulation and reduced user compliance.

The high capital cost of SWASH braces further restricts their accessibility, particularly in low-resource settings. As a result, many young orthotic users from economically disadvantaged backgrounds despite having higher activity levels and functional potential are often prescribed simpler, low-profile abduction orthoses due to financial constraints.

Several studies have also highlighted concerns related to patient comfort and acceptance of conventional hip abduction orthoses. Sergi et al. reported that users often experienced irritation and frustration, with limited perceived benefits in joint protection during rehabilitation. Similarly, Arazpour et al. noted that traditional abduction braces are costly and may cause unnecessary discomfort, negatively affecting long-term compliance.

In the current study the newly developed dynamic hip abduction brace can give dynamic motion with variable position of locking at a minimal cost. The design also provides comfort to the patient, lighter in weight, various ranges of abduction motion.

But, it is necessary to investigate the proposed prototype design mechanism through appropriate subjects in relation with their pathology to determine its effectiveness, user performance under adequate adaptation time and the joint reliability.

IV. CONCLUSION

The proposed dynamic hip brace with variable hip abduction and adjustable locking mechanism provides an innovative solution to children with spastic diplegic CP to overcome the scissoring gait and adductor tightness. Further it provides improved sitting, standing, walking functions and encourages proper closed chain muscle function. The brace also contributes in providing improved postural trunk stability by moving the COG from posterior to mid-trunk. With proper clinical indication, this dynamic hip brace has the potential to achieve favorable outcomes by improving hip alignment and muscle strength.

LIMITATIONS OF THE PROTOTYPE:

The joint mechanism of the prototype is fabricated using 3D-printed components, which have limited mechanical strength.

FUTURE RECOMMENDATIONS:

Further clinical trials should be conducted in individuals with spastic diplegic CP to evaluate the clinical effectiveness of the proposed brace. Systematic testing is required to establish the validity and reliability of the prototype within this population. In addition, the design may be refined for mass production using metallic structures to better sustain body loads, enhance joint mechanism performance, and improve overall durability.

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