

# DESIGN AND DEVELOPMENT OF A DYNAMIC “ECC” SPINAL ORTHOSIS FOR PATIENTS WITH SPONDYLOLISTHESIS

<sup>1</sup>Shrabana Kundu, <sup>2</sup> Ashmita Milan, <sup>3</sup>Dewendra Prasad, <sup>4</sup> Parthasarathi Swain

<sup>1</sup>B.P.O. Intern, <sup>2</sup>Demonstrator (P&O), <sup>3</sup>B.P.O. Programme Coordinator, <sup>4</sup>Prosthetist & Orthotist

<sup>1,2,3</sup> Department of Medical Science (Unit: Material Development - Aids & Appliances), National Institute for Empowerment of Persons with Multiple Disabilities (NIEPMD) (Divyangjan), Chennai, Tamil Nadu, India.

<sup>4</sup> Department of Prosthetics & Orthotics, Composite Regional Centre for Skill Development, Rehabilitation and Empowerment of Persons with Disabilities (CRC), Patna, Bihar, India

**Corresponding Author: Ashmita Milan**

**Email Id: ashmitamilan1996@gmail.com**

## ABSTRACT

### Objectives:

This study aims to design and evaluate a novel Dynamic ECC (Extension–Coronal plane–Control) brace incorporating a spring-assisted uniaxial joint for managing low-grade degenerative spondylolisthesis, with a focus on improving control, comfort, and user compliance.

### Materials and Methods:

A custom Dynamic ECC brace is fabricated using lightweight polypropylene bands, aluminium lateral bars, and two spring-assisted joints. A single patient with L4–L5 degenerative spondylolisthesis used the brace over a 2-month period. Pain levels (VAS score) and radiographic Lumbosacral Angle (LSA) are assessed pre- and post-intervention.

### Results:

The LSA shows no measurable change, likely due to the short intervention period. However, the patient reports a reduction in pain (VAS score from 7 to 5) and improved comfort and fit.

### Conclusions:

The Dynamic ECC brace demonstrates promising early outcomes in pain relief and comfort. Design refinements and a larger, longer-term study are needed to validate its clinical effectiveness and durability.

### Keywords:

Dynamic ECC (Extension–Coronal plane–Control) Brace, Spring-Assisted uniaxial joint, degenerative spondylolisthesis, VAS score

## INTRODUCTION

Spondylolisthesis, derived from the Greek words *spondylos* (vertebra) and *olisthesis* (slipping or dislocation), refers to the pathological anterior or posterior translation of one vertebral body over another.<sup>1</sup> The term was first introduced in 1782 by Belgian obstetrician Herbiniaux, marking one of the earliest documented descriptions of this spinal condition.<sup>2</sup> Spondylolisthesis can result from various underlying causes, including congenital abnormalities (dysplastic), defects in the pars interarticularis (isthmic), degenerative changes

associated with osteoarthritis, as well as traumatic fractures or pathological conditions such as neoplasms and osteoporosis, all of which vertebral stability and alignment is compromised.<sup>3</sup>

A study conducted in a rural South Indian population found that low-grade spondylolisthesis occurred predominantly in females (72.5%) compared to males (27.5%), with the condition most commonly affecting individuals between 40 and 60 years of age.<sup>4</sup> Spondylolisthesis most commonly occurs at the L5–S1 level, characterized by anterior translation of the L5 vertebral body over S1. The L4–L5 segment is the second most frequently affected site, particularly in cases of degenerative spondylolisthesis.<sup>5</sup>

The term "Degenerative Spondylolisthesis" was first introduced by Newman in 1963 to describe anterior slippage of a lumbar vertebral body, primarily observed in the elderly female population, and recognized as a distinct physiological entity. Later, in 1978, Kirkaldy-Willis expanded the understanding of its biomechanical characteristics, describing it as a chronic progressive condition resulting from a cascade of degenerative changes. These changes affect the periarticular vertebral complex, including the intervertebral disc and facet joints, ultimately leading to segmental instability.<sup>6</sup>

Degenerative spondylolisthesis (DS) most commonly results from intervertebral disc degeneration, which leads to disc space narrowing and settling of the motion segment. This process is typically followed by buckling of the ligamentum flavum and the development of microinstability, eventually permitting anterior slippage of the vertebral body. Unlike isthmic spondylolisthesis, which often affects younger individuals, DS predominantly occurs in adults, with its prevalence increasing with age. Notably, DS is nearly six times more common in females than in males.<sup>7,8</sup>

Degenerative spondylolisthesis (DS) most commonly occurs at the L4–L5 level, in contrast to isthmic spondylolisthesis, which typically affects the lumbosacral junction (L5–S1). The L4–L5 segment is involved 6 to 9 times more frequently than other spinal levels. This specific localization is largely attributed to the stabilizing effect of the ilio-lumbar ligaments, which provide strong anatomical support to L5, preventing its anterior displacement.<sup>9</sup>

Nonoperative treatment is typically the first-line approach in managing most cases of degenerative spondylolisthesis (DS), regardless of the presence of neurological symptoms. Conservative management options include analgesics and nonsteroidal anti-inflammatory drugs (NSAIDs) for pain control, epidural steroid injections, and physical therapy interventions such as bracing and flexion-based strengthening exercises.<sup>10</sup>

Recent research studies indicate that orthotic management, particularly with customized and rigid braces, can effectively reduce pain and improve quality of life in patients with degenerative spondylolisthesis.<sup>11</sup> Braces that reduce shear forces at affected spinal levels and maintain lumbar lordosis contribute to symptom relief. High patient satisfaction and pain reduction have been reported with rigid bracing, showing promising outcomes even after brace removal.<sup>12</sup> Additionally, innovative orthoses like the LORDACTIV, which support spinal alignment and limit harmful movements, demonstrate superior pain reduction and postural stability compared to traditional supports. Overall, orthotic intervention appears to be a valuable conservative treatment option for managing degenerative lumbar conditions including spondylolisthesis.<sup>13</sup>

Currently, there is a scarcity of research focusing on orthotic management of spondylolisthesis, with most studies concentrating on corsets and rigid braces. The Williams brace, a conventional lumbo-sacral extension-lateral control orthosis, remains the standard treatment. To address the limitations of existing designs, this study aims to develop a novel **dynamic ECC (Extension Coronal Plane Control) Brace**, incorporating a spring-assisted uniaxial joint to enhance biomechanical control and improve patient compliance. This innovative approach has the potential to advance conservative management options for spondylolisthesis.

## MATERIALS AND METHODS:

The Dynamic ECC (Extension–Coronal plane–Control) spinal orthosis is designed to manage degenerative spondylolisthesis by combining structural support with dynamic mobility. Its central feature is a spring-assisted joint mechanism that permits controlled flexion up to 30 degrees, preventing excessive forward bending while allowing functional movement during daily activities. The integrated spring mechanism aids the patient in returning to an upright posture, thereby reducing strain on paraspinal muscles and improving postural control.

The brace is engineered to be both lightweight and durable, using polypropylene (PP) sheets for the bands and aluminium for the lateral bars and joint assembly.

## Components of the Dynamic ECC Orthosis:

### Thoracic Band

Positioned approximately 3 inches below the inferior angles of the scapula, the thoracic band horizontally encircles the torso up to the mid-axillary line bilaterally. Fabricated from 5 mm thick polypropylene, it includes attachment points for the lateral bars on both sides.

### Pelvic Band

Located with its lateral ends between the greater trochanter and iliac crest, the pelvic band is also constructed from 5 mm thick polypropylene and serves as the distal attachment point for the lateral bars.

### Abdominal Corset

The abdominal corset spans from ½ inch below the xiphoid process to ½ inch above the pubic symphysis. It is made from thick cotton fabric, lined with a 4 mm Ethaflex soft liner to enhance comfort. Measuring 9.5 inches in length and 16 inches in width, the corset is secured using non-elastic Velcro hook-and-loop straps. It increases posteriorly directed intra-abdominal pressure, generating hydrostatic compression via abdominal fluid redistribution effectively offloading the spinal structures and alleviating pain.

### Spring-Assisted Joint and Lateral Bars

The aluminium joint includes a circular disc with a 30-degree slot to permit controlled forward flexion. Lateral bars, measuring 1.5 inches in width, are pivotally attached to the joint. A closed-coil spring (1 mm thickness, 12 cm length) is incorporated to assist in spinal extension and enhance return to upright posture after flexion.

### Biomechanical Principles of Bracing

The Dynamic ECC spinal orthosis functions based on the following key biomechanical principles:

#### Balanced Horizontal Force System for Extension Control

The brace employs a three-point pressure system to control excessive lumbar extension and maintain spinal alignment:

1. Corrective force is applied anteriorly through the abdominal corset, helping to resist anterior vertebral translation.
2. Supportive force from the thoracic band acts posteriorly and superiorly, stabilizing the upper trunk.
3. Supportive force from the pelvic band acts posteriorly and inferiorly, anchoring the lower torso and pelvis.

#### Increased Intracavitary Pressure

The abdominal corset increases intra-abdominal pressure, which generates hydrostatic support for the spine. This reduces axial load on the vertebral column and provides passive stabilization, aiding in pain relief and spinal unloading.

#### Kinesthetic Reminder

The orthosis serves as a proprioceptive cue, reminding the patient to maintain proper posture and limit harmful movements, particularly excessive forward flexion.

## Case History:

A 58-year-old female patient named Visuvasam, residing in KK Nagar, Chennai, presented with a two-year history of localized low back pain. She described her pain to be aggravated by prolonged standing, walking, and stair climbing, and relieved by sitting. She works in a church and has no significant past medical or orthotic history. On clinical examination, she walked independently but exhibited a limping gait with

increased lumbar lordosis during ambulation. A positive step sign was noted, and the pain was localized to the lower back, particularly around the L4–L5 region. Pain assessment using the Visual Analog Scale (VAS) revealed a score of 7 out of 10. At L4-L5, her initial radiograph (Figure 1) indicated a grade 1 anterolisthesis of L4 on L5. Based on these findings, she was diagnosed with degenerative spondylolisthesis at the L4–L5 level. The patient initially reported to KK Nagar Hospital for treatment and was subsequently referred to NIEPMD, Chennai for appropriate orthotic management. As a part of a conservative management approach, she was prescribed with the Dynamic ECC (Extension Coronal plane Control) spinal orthosis, designed to reduce shear forces, improve postural support, and relieve pain while allowing controlled functional movement.



Figure- 01: Lateral X-ray of lumbar spine

### Methodology:

After the patient consented to our treatment plan, the fabrication procedure begins with taking patient's measurement in the prone position. Key anatomical landmarks like inferior angle of the scapula, L3–L4 vertebrae, and iliac crest were marked. A negative cast of the lower back was obtained using Plaster of Paris bandages, reinforced, and poured with POP slurry to create a positive mold. The mold was later rectified to match spinal contours reducing excessive lordosis and adding relief over pressure-sensitive areas.



Figure- 02: Casting procedure

A 5 mm polypropylene sheet was heated to 210 °C and draped over the positive mold to form the thoracic and pelvic bands. These bands were later trimmed and smoothed along defined trimlines: the thoracic band extending 3 inches below the inferior angle of the scapula and the pelvic band positioned between the iliac crest and greater trochanter.

The spring assisted joint was fabricated by attaching the aluminium lateral bars to the circular disc with a 30° slot, which allowed controlled flexion. A steel coil spring was fixed between the disc and lateral bar, enabling assisted return to an upright posture. The joint was riveted to both the pelvic and thoracic bands bilaterally.



Figure- 03: (Brace with spring assisted joint)

An abdominal corset was prepared from cotton fabric with ethaflex lining and attached anteriorly. A fitment trial was performed, followed by minor adjustments to improve alignment and comfort.

After the trial and checkout, the patient was discharged with instructions on the use of the dynamic ECC spinal brace. She was advised to wear the brace for 8–10 hours daily, with removal allowed 30 minutes before and after meals and during sleep. A follow-up was scheduled after two months of brace use, during which a post-fitment X-ray was obtained to assess listhesis measurement and lumbo sacral angle (LSA), and Visual Analogue Scale (VAS) scores were obtained.



A



B



C

Figure- 04: (A: Anterior view, B: Lateral view, C: Posterior view of Dynamic ECC orthosis)

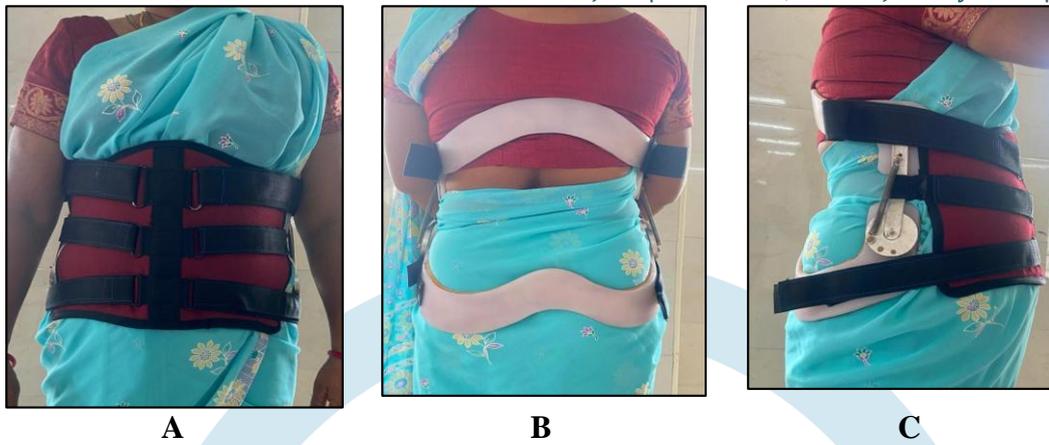


Figure- 05: (A: Anterior view, B: Posterior view, C: Lateral view of patient with dynamic ECC spinal orthosis)

**RESULT AND DISCUSSION**

After the 2 months of intervention period the followings post-fitment data were collected using Meyerding grading for listhesis measurement, LSA and pain levels were assessed through VAS score.



Figure- 06: Pre-fitment X-ray of lumbar spine



Figure- 07: Post-fitment X-ray of lumbar spine

**PRE AND POST-FITMENT DATA COLLECTION**

| Parameter                | Pre-Fitment | Post-Fitment |
|--------------------------|-------------|--------------|
| Meyerding Grading        | Grade I     | Grade I      |
| Lumbo-sacral Angle (LSA) | 60°         | 60°          |
| Pain Score (VAS)         | 7/10        | 5/10         |

The comparison of pre and post fitment data showed no increase or decrease in listhesis measurement viewed in X-ray. The LSA angle also showed no measurable changes, whereas the VAS score showed a reduction in score, giving a symptomatic relief of pain.

Degenerative spondylolisthesis is a condition commonly associated with aging, characterized by the forward slipping of one vertebra over another. It has a higher prevalence in females, likely due to increased ligament laxity and hormonal influences. Most cases are low grade (Meyerding grade I or II) and present with symptoms like lower back and leg pain. Conservative management, including medication, physiotherapy, and spinal bracing, is often the preferred initial approach.

Previous research has demonstrated that lumbosacral braces can significantly reduce vertebral slippage, particularly at the L5–S1 level. However, these studies generally involved longer treatment durations. In contrast, the current study focuses on a patient with L4–L5 spondylolisthesis and utilizes the Dynamic ECC (Extension–Coronal plane–Control) spinal orthosis. Although no radiographic improvement in Lumbosacral Angle (LSA) was noted over a 2-month period, the patient experienced a reduction in pain (VAS score reduced from 7 to 5) and improved comfort and compliance while wearing the brace.

The case also highlighted areas for design refinement, including difficulty in independently donning the abdominal corset and the potential for mechanical fatigue in the spring mechanism over prolonged use. Despite these challenges, the use of lightweight polypropylene and aluminium components contributed to a comfortable and supportive fit. A longer intervention period and larger study population are recommended to fully evaluate the orthosis's long-term efficacy and durability.

## CONCLUSION

The present study demonstrates that the dynamic ECC spinal orthosis offers promising benefits as a conservative treatment option for patients with degenerative spondylolisthesis at the L4-L5 level. While no significant radiographic changes, such as alterations in the Lumbosacral Angle, were observed during the relatively short two-month intervention, the patient experienced a meaningful reduction in pain and improved overall comfort and compliance with brace use. These symptomatic improvements suggest that the dynamic brace's design, incorporating spring-assisted control and lightweight materials, effectively supports spinal alignment and reduces muscular strain during movement. The dynamic nature of the orthosis, allowing controlled flexion while assisting return to an upright posture, may contribute to better functional outcomes compared to traditional rigid braces. It is reasonable to anticipate that longer-term use could lead to measurable biomechanical improvements, including decreased vertebral slippage and stabilization of spinal segments. Therefore, this dynamic orthotic intervention holds potential as a valuable component of non-surgical management for degenerative spondylolisthesis. Future studies with extended treatment durations, larger sample sizes, and comprehensive follow-up are essential to validate these preliminary findings and to explore the brace's long-term efficacy in pain reduction, functional improvement, and structural stabilization.

### Limitation:

The study is limited by its short intervention period, which restricts observation of long-term effects. It involves only one patient, limiting generalizability. Pain assessment was subjective, and the brace had usability issues like difficulty in donning and potential spring wear. Lack of a control group also limits comparison with other treatments.

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