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Clinical Trajectories in Traumatic and Non-Traumatic Cervical Spondylotic Myelopathy: A Retrospective Cohort Study and Cluster Analysis to Guide Surgical Decision-Making

Brando Guarrera*, M. Todoverto, S. Rapisarda, Y. Ceccaroni

Department of Neurosurgery, Ospedale dell'Angelo, Venice, Italy

Abstract

Background: Cervical spondylotic myelopathy (CSM) stems from either chronic degenerative changes or traumatic mechanisms. Distinguishing between these etiologies is crucial, yet identifying which patients benefit most from surgery remains challenging. This study aims to evaluate how trauma history, spinal alignment, and patient profiling influence clinical outcomes.

Methods: A retrospective cohort study was conducted on 153 patients treated at the "Ospedale dell'Angelo" (Venice, Italy). Patients were assessed using the modified Japanese Orthopedic Association (mJOA) score. Variables included trauma history, spinal alignment (Cervical Lordosis, SVA, T1 Slope), and ASA score. Statistical analysis employed linear regression and K-means cluster analysis to identify homogeneous patient profiles.

Results: Patients with a history of mild trauma showed a trend toward greater improvement compared to non-traumatic cases (mJOA improvement: +1.61 vs +0.33, p=0.074). Surprisingly, patients with straight spinal alignment achieved higher recovery (+1.29 points) than those in the kyphotic (-0.08) or lordotic (+0.15) groups. Cluster analysis identified a specific subgroup of non-surgical trauma patients who achieved remarkable recovery (+5.00 points) without intervention.

Conclusion: Trauma history acts as a potential catalyst for neurological recovery. While surgery remains the standard for unstable cases, our data suggest that a neutral (straight) alignment is associated with favorable outcomes, and that a subset of trauma patients can recover significantly with conservative management.

Keywords: Cervical myelopathy; surgical outcomes; trauma; spinal alignment; patient selection.

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Introduction

Cervical spondylotic myelopathy (CSM) is a leading cause of spinal cord dysfunction in adults. Its pathophysiology typically diverges into two distinct pathways: non-traumatic CSM, arising from progressive degenerative changes like osteophyte formation and ligament hypertrophy, and traumatic CSM, triggered by cervical injuries that exacerbate existing compression or precipitate acute neurological deterioration.[1-4]

While degenerative cervical myelopathy (DCM) often follows a chronic course with stepwise decline—where up to 62% of patients deteriorate within 3–6 years without intervention[5]—trauma-related CSM can precipitate acute neurological deterioration, particularly in patients with pre-existing stenosis.[6] Surgical decompression is widely considered the gold standard for halting progression and improving outcomes.[7-9] However, determining the optimal treatment strategy remains complex, as factors such as spinal alignment, age, and preoperative health status interact in unpredictable ways.[10-12]

Research Gap and Novelty

Despite extensive literature on DCM, there is a paucity of research directly comparing the clinical trajectories of traumatic versus non-traumatic subtypes using advanced patient profiling. Furthermore, the specific impact of *mild* trauma on surgical outcomes is often under-reported. This study addresses this gap by integrating traditional statistical methods with Cluster Analysis. By defining specific patient phenotypes based on trauma history and sagittal alignment, we aim to provide actionable insights to refine surgical indications and personalize care.

Materials and Methods

Study Design and Ethics

This retrospective cohort study analyzed clinical

*Correspondence to: Dr. Guarrera Brando, Email: brandoguarrera@gmail.com

outcomes in 153 patients treated for cervical myelopathy between 2016 and 2023 at the Neurosurgery Department of "Ospedale dell' Angelo" in Venice, Italy. The study was conducted in accordance with the Declaration of Helsinki. Informed consent was obtained for the processing of clinical data.

Participants and Inclusion Criteria

Inclusion criteria were: (1) Confirmed diagnosis of CSM; (2) Follow-up data of at least 1 month (range 1–48 months); and (3) Complete pre- and post-treatment mJOA scores. Patients were categorized into two groups:

1. **Non-Traumatic Group:** Patients with progressive symptoms and no history of trauma.
2. **Traumatic Group:** Patients with a history of trauma occurring after the onset of mild symptoms. In our cohort, "trauma" was defined as mild events, including hyperextension injuries, sudden neck jerks, light whiplash, or low-impact falls.

Radiological Assessment of Spinal Alignment

To objectively evaluate sagittal balance, we utilized standard radiographic parameters measured on lateral radiographs, according to data presented in the literature [13]:

- **Cervical Lordosis (CL):** Measured as the Cobb angle between C2 and C7.
- **Sagittal Vertical Axis (SVA):** To quantify anterior-posterior balance.
- **T1 Slope (T1S):** The inclination of the T1 vertebra.
- **Thoracic Inlet Angle (TIA):** An indicator of alignment requirements. Patients were classified into Kyphotic, Lordotic, or Straight alignment based on these parameters.

Statistical Analysis

Data analysis was performed using Python and SPSS. We employed independent t-tests to compare outcomes between groups and linear regression (OLS) to assess variable effects. K-means Cluster Analysis was used to identify homogeneous patient phenotypes. Statistical significance was set at $p<0.05$.

Results

Demographics and Baseline Characteristics

The cohort consisted of 153 patients with a mean age of 61.9 ± 15.3 years. The majority of patients underwent surgical treatment (88.9%), while 11.1% were managed conservatively. Baseline characteristics, stratified by trauma history, are summarized in Table 1. The trauma group was slightly younger (58.3 years) compared to the non-trauma group (64.1 years).

Impact of Trauma on Clinical Recovery

Analysis of clinical outcomes revealed that patients with a history of mild trauma achieved a greater mean improvement in mJOA scores (+1.61 points) than those without trauma (+0.33 points). Although this difference showed a strong positive trend, it did not reach strict statistical significance ($p=0.074$), likely due to sample size variability (Fig. 1).

Spinal Alignment Outcomes

Contrary to the hypothesis that lordotic correction is always superior, our data indicated that patients with Straight preoperative alignment achieved the greatest mean improvement in mJOA (+1.29 points). In comparison, patients with Kyphotic (-0.08) and Lordotic (+0.15) alignment showed minimal mean improvement in this cohort (Fig. 2). The difference across groups was not statistically significant ($p=0.23$), suggesting that a neutral "straight" profile may be sufficient for favorable recovery in this specific population.

Cluster Analysis: Patient Phenotypes

K-means clustering identified three distinct patient profiles with divergent outcomes (Table 2):

- **Cluster 1 (Standard Degenerative):** Older patients without trauma treated surgically, showing stable but limited improvement (+0.09).
- **Cluster 2 (Surgical Trauma Responders):** Younger patients (mean 57y) with trauma history treated surgically, showing solid improvement (+1.14).
- **Cluster 3 (Conservative High Responders):** A distinct subgroup of patients with a history of trauma who were managed conservatively and achieved the highest recovery (+5.00 points).

Discussion

Trauma as a Catalyst for Recovery

Our findings demonstrate a notable trend where mild trauma history is associated with better clinical recovery (Fig. 1). This supports the "pincer mechanism" theory: in patients with pre-existing stenosis, mild hyperextension injuries cause transient cord compression.[1,3] Since the neurological deficit is partly due to this acute "shock" rather than chronic structural damage alone, the potential for reversibility—

Table 1. Demographic and clinical characteristics of the patient cohort.

Variable	Total cohort (n=153)	Trauma Group (n=57)	No Trauma Group (n=96)
Age (Mean ± SD)	61.9 ± 15.3	58.3 ± 18.6	64.1 ± 12.5
Treatment Type			
Surgery	136 (88.9%)	45 (78.9%)	91 (94.8%)
Conservative	17 (11.1%)	12 (21.1%)	5 (5.2%)
Spinal Alignment			
Kyphotic	21 (13.7%)	12 (21.1%)	9 (9.4%)
Lordotic	44 (28.8%)	20 (35.1%)	24 (25.0%)
Straight	52 (34.0%)	14 (24.6%)	38 (39.6%)
Unknown / Other	36 (23.5%)	11 (19.3%)	25 (26.0%)

Demographic and clinical characteristics of the patient cohort stratified by trauma history. The trauma group was younger on average and had a higher proportion of conservative management compared to the non-trauma group.

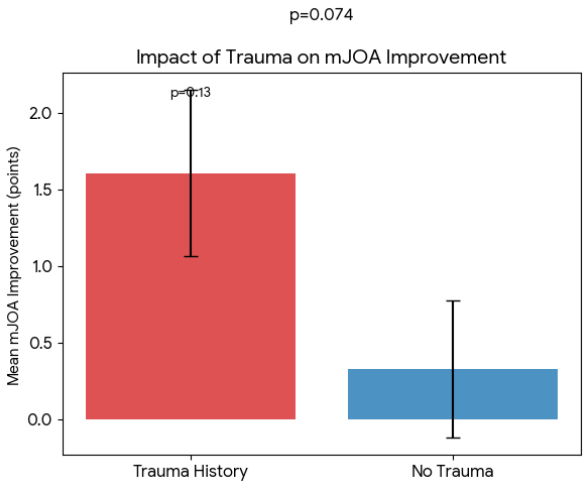

Figure 1. Comparison of mean mJOA score improvement between patients with and without a history of mild trauma. The trauma group showed a trend toward greater neurological recovery (mean +1.61 points vs +0.33 points, p=0.074).

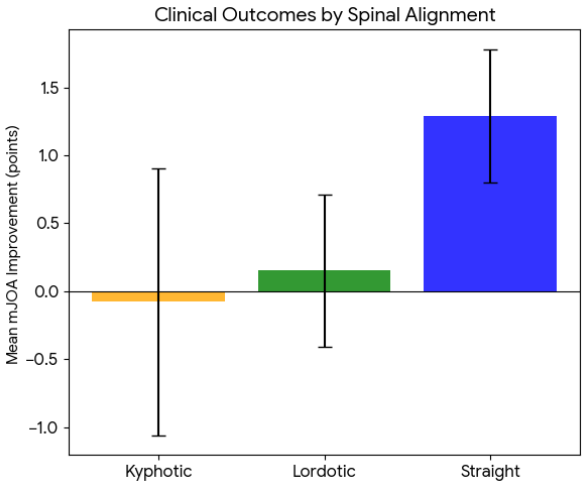

Figure 2. Post-treatment mJOA improvement based on preoperative spinal alignment. Contrary to traditional expectations, patients with straight alignment in this cohort achieved the highest mean improvement compared to kyphotic or lordotic groups.

Table 2. Patient phenotypes identified via K-means cluster analysis.

Cluster	Profile Description	Key Features	Mean mJOA Improvement	Clinical Insight
Cluster 1	**Standard Degenerative** (n=56)	Older (64y), No Trauma, Surgical	+0.09	Stable outcome; surgery prevents decline but yields limited gain.
Cluster 2	**Surgical trauma** (n=28)	Young (57y), Trauma History, Surgical	+1.14	**Good Responders:** Trauma acts as a catalyst for surgical recovery.
Cluster 3	**Conservative Responders** (n=7)	Older (68y), **Trauma History**, **Non-Surgical**	**+5.00**	**Unexpected High Recovery:** A subgroup of trauma patients recovers remarkably well without surgery.

Patient phenotypes identified via K-means cluster analysis. Cluster 3 highlights a distinct subgroup of trauma patients who achieved significant recovery with conservative management alone.

either through surgery or spontaneous resolution—appears higher than in pure degenerative cases.

Re-evaluating Spinal Alignment

While literature emphasizes the restoration of lordosis,[10] our study found that patients with straight alignment had the best outcomes (Fig. 2). This unexpected finding suggests that for many CSM patients, a "neutral" straight spine may represent a stable, compensated state that does not necessarily require aggressive lordotic correction. It implies that maintaining a balanced, straight alignment can be a valid surgical goal, potentially reducing the need for extensive osteotomies or hyperlordotic cages.

The "Cluster 3" Phenomenon: Recovery without Surgery

One of the most clinically relevant findings is Cluster 3 (Table 2). This group of trauma patients achieved remarkable recovery (+5.00 points) without surgery. It is plausible that these patients suffered primarily from cord edema or transient neurapraxia rather than structural instability. Distinguishing this phenotype—characterized by 'soft' injury and stable dynamic X-rays—is crucial to avoid unnecessary surgeries.

Limitations

This study is limited by its retrospective design and the variable follow-up duration. The unexpected results regarding alignment warrant further investigation in larger, multi-center cohorts.

Conclusion

1. **Trauma History:** Is a positive prognostic indicator for recovery. Patients with mild trauma tend to improve more than non-traumatic degenerative cases.
2. **Alignment:** Straight alignment is associated with favorable outcomes, challenging the dogma that lordosis must always be aggressively restored.
3. **Conservative Management:** A specific subset of trauma patients (Cluster 3) recovers exceptionally well without surgery. Identifying these patients early can prevent overtreatment.

Acknowledgments

None.

Ethical consideration

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committees and with the 1964 Helsinki Declaration and its later amendments, or with comparable ethical

standards. The Ethics Committee of Dell'Angelo Hospital approved the study. Informed consent was obtained from all individual participants included in the study.

Competing Interests

The authors declare no conflict of interest.

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