Thoracic myelopathy due to ossification of ligamentum flavum: a retrospective analysis of predictors of surgical outcome and factors affecting preoperative neurological status

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Abstract Despite good posterior decompression of thoracic myelopathy due to ossification of ligamentum flavum (OLF), recovery varies widely from 25 to 100%. Neurological status on presentation also varies widely in different patients. We, therefore retrospectively studied relation of various clinical and magnetic resonance imaging (MRI) parameters with preoperative neurological status and postoperative recovery in 25 patients who underwent decompressive laminectomy for thoracic myelopathy due to OLF. Patients were assessed using leg-trunk-bladder scores of JOA scale and recovery rate (RR) was calculated as $RR = \frac{\text{postoperative score} - \text{preoperative score}}{11 - \text{preoperative score}} \times 100$. With Pearson's correlation, postoperative recovery rate (RR) significantly correlated with preoperative duration of symptoms, JOA score, sensory JOA score, canal grade, dural canal-body ratio (DCBR), intramedullary signal size (ISS), and intramedullary signal type (IST) on MRI. On MRI, two types of signal changes were identified: normal in T1/hyperintense in T2 representing cord edema and hypointense in T1/hyperintense in T2 representing cystic changes indicating lesser and higher grades, respectively. Presence or absence of signal changes did not correlate with postoperative recovery; but whenever present, ISS greater than 15 mm significantly compromised recovery. Multiple regression analysis (MRA) identified preoperative duration of symptoms and preoperative ISS as significant predictors of

postoperative outcome. Based on MRA, we formulated a multiple regression equation to predict RR as Predicted $RR = 83.4 + (0.1 \times \text{age in years}) - (0.7 \times \text{preoperative duration of symptoms in months}) + (1.5 \times \text{preoperative JOA score}) + (0.2 \times \text{preoperative canal grade in percentage}) - (2.5 \times \text{ISS in mm}) - (1.5 \times \text{IST in grade})$. Though age, preoperative anal sensations, spasticity, canal grade, DCBR, ISS, and IST significantly correlated with preoperative neurological status, MRA identified ISS as most important factor determining preoperative neurological status. Preoperative duration of symptoms and developmentally narrow canal had no influence on preoperative neurological status. Patients with developmentally narrow canal showed significant correlation with younger age at onset of myelopathy. To conclude, only independent factor determining preoperative neurological status is ISS. Predictors of postoperative recovery are preoperative duration of symptoms and ISS. Postoperative recovery can be predicted by formulated equation.

Keywords Ossification of ligamentum flavum · Thoracic spine · Thoracic myelopathy · Predictors of outcome · Thoracic stenosis

Introduction

Ossification of ligamentum flavum (OLF) is a well-known cause of progressive thoracic myelopathy reported mainly in Japanese patients [1–11]. Few series are reported from Korea, China, India, Middle East, and Caribbean with sporadic case reports in Caucasians [12–24]. It commonly involves lower thoracic spine (T9–T12) with upper thoracic spine (T1–T4) being the next common site [11, 15, 16, 25]. The commonest mode of treatment is posterior

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Fig. 1 MRI showing T11–12 round OLF with hyperintense intramedullary signal change in T2 weighted image (a), which is hypointense in T1 weighted image (b) signifying cystic changes or syrinx

decompression by laminectomy, although laminoplasty has been described as an alternative due to late neurological deterioration and pain secondary to postlaminectomy kyphosis [26]. There is a wide variation in neurological status of patients on presentation. Despite good surgical decompression, recovery varies widely from 25 to 100% [16, 26]. Prognostic guidelines are still unclear and make it very difficult for the surgeon to predict postoperative recovery.

This study aimed at retrospective analysis of data of 25 Indian patients who underwent posterior decompression by laminectomy for thoracic myelopathy due to OLF. Correlation of various clinical and magnetic resonance imaging (MRI) parameters with preoperative neurological status and recovery was studied. Related factors were independently analyzed with recovery to find predictors of outcome and an equation to predict postoperative recovery was formulated.

Materials and methods

The study included retrospective collection of data of patients operated for thoracic myelopathy due to OLF at Indian Spinal Injuries Center between 2002 and 2008. Exclusion criteria were other causes of thoracic myelopathy like associated ossification of posterior longitudinal ligament or disc herniation which might need anterior decompression.

The study group comprised of 25 patients (18 males, 7 females) with age at surgery of 60.4 ± 12.9 (mean $\pm$ SD) years (range 44–82), postoperatively followed for 30.3 ± 12.1 months (range 12–65). Preoperative duration

of symptoms was 20.7 ± 25.7 months (range 1 week to 84 months). Symptoms were gradual in onset in 23 patients while two patients presented after minor trauma.

All patients underwent decompressive laminectomy of symptomatic levels. Dural adhesions were found in 13 patients and floating of adherent fragment was done to achieve decompression. Instrumented fusion of decompressed levels was carried out when three or more levels were laminectomized. A total of 39 levels were operated (1.56 ± 0.92). In decreasing order, levels were T10–T11 (12), T11–T12 (10), T9–T10 (6), T12–L1 (3), T2–3 (3), T3–4 (2), T4–5 (1), T5–6 (1), and T6–T7 (1). There was 1, 2, and 3 or 4 levels involvement in 16, 6, and 3 patients, respectively.

Patient records were examined for preoperative clinical and MRI parameters. All patients underwent clinical assessment and MRI at final follow-up.

Morphology of OLF

On sagittal MRI, round (Fig. 1) or beak types of OLF were identified (Fig. 2). OLF morphology was round in 21 and beak type in four patients.

Definitions, measurements, and scales used:

1. Anteroposterior (AP) and transverse dural canal diameter were measured at maximum stenosed level on axial T2 weighted MRI.
2. Preoperative canal grade expressed as percentage of normal dural canal diameter was calculated on axial T2 weighted MRI as:

$$\frac{\text{AP dural canal diameter of stenosed level}}{\text{normal dural canal diameter}} \times 100$$

Fig. 2 MRI showing T1–T2 beak OLF with hyperintense intramedullary signal change in T2 weighted image (a), which is isointense in T1 weighted image (b) signifying cord edema, inflammation, ischemia, or myelomalacia

Normal dural canal diameter was calculated as an average diameter of adjacent non-stenosed segments. Canal stenosis was graded into mild (>75% of normal), moderate (51–75% of normal), and severe ($\leq 50\%$ of normal) categories. Eighteen patients had moderate and seven had severe stenosis.

3. Preoperative dural canal/body ratio (DCBR) was calculated on axial T2 weighted MRI as:

AP dural canal diameter/AP mid-body diameter

4. Bony canal-body ratio (BCBR) was calculated on lateral radiograph as:

AP bony canal diameter/AP mid-body diameter

Developmentally narrow canal was defined as BCBR < 0.4 . It was found in three patients.

5. Spasticity was assessed with Ashworth scale [27].
6. Preoperative intramedullary signal size (ISS) measured vertically on sagittal T2 weighted MRI. It ranged from 0 to 30.8 mm (13.1 ± 8.3 mm).
7. Two types of intramedullary signals were identified on MRI. (a) Normal in T1 and hyperintense in T2 weighted image—indicating cord edema, inflammation, ischemia or myelomalacia (Fig. 2) [28]. (b) Hypointense in T1 and hyperintense in T2 weighted image—indicating cystic necrosis or syrinx (Fig. 1) [29].
8. Pre and postoperative neurological status was recorded using leg-trunk-bladder scores of revised Japanese

Orthopaedic Association (JOA) scale (Table 1). Recovery rate (RR) was calculated as follows:

$$\text{RR} = \frac{\text{Postoperative JOA} - \text{Preoperative JOA}}{\text{Preoperative JOA} / 11} \times 100$$

Surgical outcomes were graded in five groups based on RR as excellent (76–100%), good (51–75%), fair (26–50%), unchanged (0–25%), and worsened ($< 0\%$).

Statistical analysis

Pearson's correlation coefficient was used to test correlation between various factors and RR or preoperative neurological status. Differences between two and three groups were analyzed with *t* test and analysis of variance (ANOVA), respectively. Multiple regression analysis (MRA) was carried out to identify independent factors associated with RR and preoperative neurological status. Based on MRA, a multiple regression equation (MRE) was formulated to predict RR. Data were analyzed using the statistical package for the social sciences (SPSS, Inc. Chicago, IL, USA).

Results

Mean pre and postoperative JOA score were 4.7 ± 2.1 and 8.4 ± 3 , respectively. Various MRI measurements were as

Table 1 Revised Japanese orthopaedic association scoring system

	Score
Motor function: lower extremity	
Unable to stand up and walk by any means	0
Able to stand up but unable to walk	0.5
Unable to walk without a cane or other support on a level	1
Able to walk without support but with a clumsy gait	1.5
Walks independently on a level but needs support on stairs	2
Able to walk independently when going upstairs, but needs support when going downstairs	2.5
Capable of fast but clumsy walking	3
Normal	4
Sensory function: lower extremity	
Complete loss of touch and pain sensation	0
50% or less normal sensation and/or severe pain or numbness	0.5
More than 60% normal sensation and/or moderate pain or numbness	1
Subjective numbness of slight degree without any objective sensory deficit	1.5
Normal	2
Sensory function: trunk	
Complete loss of touch and pain sensation	0
50% or less normal sensation and/or severe pain or numbness	0.5
More than 60% normal sensation and/or moderate pain or numbness	1
Subjective numbness of slight degree without any objective sensory deficit	1.5
Normal	2
Bladder function	
Urinary retention and/or incontinence	0
Sense of retention and/or dribbling and/or thin stream and/or incomplete continence	1
Urinary retardation and/or pollakiuria	2
Normal	3
Total score	11

per Table 2. Results were excellent in 13 (52%), good in 5 (20%), fair in 3 (12%), unchanged in 3 (12%), and worsened in 1 (4%) patient. Complications included two patients with neurological deterioration and one with dural tear. One patient with neurological deterioration made good recovery at final follow-up of 23 months while the other remained worsened even at 28 months. There were no infections, postlaminectomy instability or neurological deterioration following recovery.

IST was divided into three groups; (1) no signal changes, (2) cord edema [Normal (T1)/Hyper (T2)], (3) cystic changes [Hypo (T1)/Hyper (T2)]. ANOVA demonstrated significant differences in recovery between these groups. Though recovery in group 1 was slightly better than group 2, the differences were statistically insignificant. However,

Table 2 Various MRI measurements

MRI parameter	Mean $\pm$ SD	Range
Preoperative AP diameter (mm)	5.7 $\pm$ 1.5	4.3–9.9
Preoperative Transverse diameter (mm)	8.8 $\pm$ 2.1	5.1–11.9
Preoperative canal grade (%)	55.8 $\pm$ 10.2	31.3–68.8
Preoperative DCBR	0.26 $\pm$ 0.07	0.13–0.40
Preoperative ISS (mm)	13.1 $\pm$ 8.3	0–30.8
Improvement in AP diameter (mm)	2.3 $\pm$ 0.9	0–4.1
Improvement in transverse diameter (mm)	1.4 $\pm$ 0.3	0–2.2
Improvement in canal grade (%)	15.1 $\pm$ 6.8	5.2–32.3

recovery significantly declined as IST changed from edema to cystic (Table 3). This led us to grade IST into grade 1 as no signal, grade 2 as cord edema, and grade 3 as cystic changes.

ISS was divided into three groups as no signal (group A) <15 mm (group B), and $\geq$ 15 mm (group C). Recovery significantly differed in three groups. Presence or absence of intramedullary signal changes had no influence on recovery; but whenever present, ISS greater than 15 mm significantly decreased chances of recovery (Table 4).

Associated cervical or lumbar stenosis patients were also grouped into those who were decompressed and persistent categories (Table 5). Recovery was found to be significantly better in the decompressed group than persistent ones. Interestingly, decompression of associated cervical or lumbar stenosis led to better recovery compared with those without any associated stenosis, though the differences were statistically insignificant.

Correlation of all clinical and MRI parameters with recovery is shown in Table 6. Factors significantly correlated with recovery were preoperative duration of symptoms, preoperative JOA score, preoperative sensory JOA score, preoperative canal grade, preoperative DCBR, preoperative ISS, and preoperative IST. Other factors had no correlation with recovery; notably, presence or absence of signal changes did not correlate with postoperative recovery.

Based on these findings, we selected six parameters shown in Table 7 for MRA to identify independent factors related to postoperative recovery or in other words, outcome predictors. Sensory JOA score and preoperative DCBR were excluded from the MRA as the former represents a subgroup of JOA score, while the latter also represents the severity of canal stenosis; therefore, using them along with full JOA score and canal grade would give rise to error in MRE. Age was included because we believed that it is not prudent to formulate an equation without this parameter and also to exclude any possibility of type 2 error on univariate analysis.

MRA identified preoperative duration of symptoms and preoperative ISS as significant predictors of postoperative outcome. The adjusted R^2 was 0.492 indicating 49.2% of

Table 3 Intramedullary signal type and recovery rate

Intramedullary signal type (T1/T2)	No. of patients	Age (years)	Duration of symptoms (months)	Preoperative JOA score	RR (%)
Group 1: absent signal	3	58.5 ± 14.3	14.6 ± 19.5	5.7 ± 2.3	85.5 ± 6.9
Group 2: normal/Hi (edema)	16	60.2 ± 12.4	20.7 ± 22.9	5.1 ± 2.1	73.3 ± 19.7
Group 3: low/Hi (cystic changes)	6	63.8 ± 11.3	27.3 ± 28.7	3.1 ± 1.8	22.8 ± 29.9

$P = 0.0001$ (Group 1, 2 and 3) by ANOVA

$P = 0.318$ (Group 1 and 2); $P = 0.009$ (Group 1 and 3); $P < 0.001$ (Group 2 and 3) by t test

$P = 0.182$ (Group 1 and 2 + 3), $P < 0.001$ (Group 1 + 2 and 3) by t test

Statistical significance was set at a $P < 0.05$

Table 4 Intramedullary signal size and recovery rate

Intramedullary signal size (T2)	No of patients	Age (years)	Duration of symptoms (months)	Preoperative JOA score	RR (%)
Group A: no signal	3	58.5 ± 14.3	14.6 ± 19.5	5.7 ± 2.3	85.5 ± 6.9
Group B: (size <15 mm)	15	59.1 ± 13.4	19.8 ± 23.3	5.2 ± 2.4	76.8 ± 18.6
Group C: (size ≥15 mm)	7	64.3 ± 11.3	25.1 ± 29.1	2.8 ± 2.1	36.9 ± 29.2

$P = 0.0001$ (Group A, B and C) by ANOVA

$P = 0.413$ (Group A and B); $P = 0.039$ (Group A and C); $P = 0.008$ (Group B and C) by t test

$P = 0.182$ (Group A and B + C), $P = 0.009$ (Group A + B and C) by t test

Statistical significance was set at a $P < 0.05$

Table 5 Associated cervical/lumbar stenosis and recovery rate

Cervical/lumbar stenosis	No of patients	Age (years)	Duration of symptoms (months)	Preoperative JOA score	RR (%)
Group A: absent	19	60.3 ± 13.5	19.2 ± 24.7	5.3 ± 2.1	66.1 ± 26.8
Group B: decompressed	4	58.2 ± 11.3	17.3 ± 20.2	5.9 ± 2.7	81.1 ± 11.7
Group C: persistent	2	63.1 ± 12.8	24.4 ± 28.5	2.0 ± 1.4	−2.25 ± 10.9

$P = 0.0022$ (Group A, B and C) by ANOVA

$P = 0.288$ (Group A and B); $P = 0.002$ (Group A and C); $P = 0.001$ (Group B and C) by t test

$P = 0.399$ (Group A and B + C), $P = 0.001$ (Group A + B and C) by t test

Statistical significance was set at a $P < 0.05$

the variability of recovery rate being explained by the variability of all these six variables, out of which preoperative duration of symptoms and preoperative ISS were significant. Since the other four factors also contributed to the variability of recovery rate, we believed that predicting the RR using only two factors would be inadequate in a clinical setting and including all six factors would improve predictability of recovery rate. Therefore, simplified MRE to predict RR was as follows:

$$\begin{aligned} \text{Predicted RR} = & 83.4 + (0.1 \times \text{age in years}) \\ & - (0.7 \times \text{preoperative duration of symptoms in months}) \\ & + (1.5 \times \text{preoperative JOA score}) \\ & + (0.2 \times \text{preoperative canal grade in percentage}) \\ & - (2.5 \times \text{ISS in mm}) - (1.5 \times \text{IST in grade}). \end{aligned}$$

Factors that significantly correlated with preoperative neurological status were age, preoperative anal sensations,

preoperative spasticity, preoperative canal grade, preoperative DCBR, preoperative ISS, and preoperative IST on MRI (Table 8). All other factors had no correlation with preoperative neurological status. But on MRA only preoperative ISS qualified as significant factor determining preoperative neurological status (Table 9). Remaining factors had no impact on preoperative neurological status; notably, preoperative duration of symptoms and developmentally narrow canal. Patients with developmentally narrow canal showed significant correlation with younger age at onset of myelopathy ($P = 0.023$, $r = 0.4516$).

Discussion

Age and sex

Age or sex does not correlate with RR as reported [3, 5, 7, 8, 10, 12, 13, 16, 17], except one study [1] reporting

Table 6 Pearson's correlation with recovery rate

Clinical factor	<i>r</i> coefficient	<i>P</i> value	Radiological factor	<i>r</i> coefficient	<i>P</i> value
Age	−0.2305	0.268	Preop AP diameter	0.3757	0.064
Sex	0.1042	0.504	Preop transverse diameter	0.3433	0.093
Duration	−0.5108	0.009*	Preop canal grade	0.3992	0.048*
JOA	0.4327	0.031*	Preop DCBR	0.5014	0.011*
Motor	0.3447	0.091	Presence or absence of cord signal	−0.3398	0.097
Sensory	0.5521	0.018*	Signal size	−0.5950	0.002*
Bladder	0.3491	0.087	Signal type	0.4094	0.042*
Anal sensations	0.3328	0.104	Improvement in AP diameter	0.2799	0.175
Spasticity	−0.0892	0.671	Imp in transverse diameter	0.2488	0.230
Associated trauma	0.1811	0.386	Improvement in canal grade	0.3227	0.116
Dural adhesions	−0.2785	0.178	No of segments involved	−0.0851	0.686
Cervical/lumbar stenosis	−0.2239	0.282	OLF morphology	−0.1779	0.395
			Level of OLF	0.2761	0.182
			Developmentally narrow canal	−0.3407	0.096

Qualitative data were converted to quantitative by numbers as: male, 1; female, 2; anal sensations: absent, 1; present, 2; no trauma, 1; associated trauma, 2; dural adhesion: absent, 1; present, 2; associated cervical/lumbar stenosis: no, 1; decompressed, 2; persistent, 3; intramedullary signal: absent, 1; present, 2; OLF morphology: round-, 1; beak, 2; signal type (T1/T2): absent, 1; normal/high (edema), 2; low/high (cystic), 3; level: T1–T4, 1; T4–T7, 2; T9–L1, 3; developmentally narrow canal: absent, 1; present, 2

* Statistically significant at $P < 0.05$

Table 7 Independent factors associated with recovery rate with MRA

Factor	Partial regression coefficient (B)	Standardized partial regression coefficient (Beta)	<i>P</i> value
Age	0.09486	0.02854	0.8421
Duration	−0.71131	−0.44657	0.0485*
JOA	1.48592	0.09943	0.4274
Preop canal grade	0.22407	0.08212	0.5236
Signal size	−2.54131	−0.52130	0.0243*
Signal type	−1.53161	−0.12187	0.2168
	83.40335 (constant)		

Qualitative data were converted to quantitative by numbers as: signal type (T1/T2): absent, 1; normal/high (edema), 2; low/high (cystic), 3

* Statistically significant at $P < 0.05$

correlation of age with RR. Kojima [30] reported good postoperative recovery in younger patients despite severe involvement indicating good plasticity of spinal neurons. The correlation would have been evident if the entity was equally common in younger age group, giving chance to compare recovery between reasonably broader spectrum of age with an adequate sample size of young patients. No study has reported correlation between sex and recovery. Preoperative neurological status correlates with age indicating progressive nature of the condition with old age. Sex has no correlation with preoperative neurological status.

Preoperative duration of symptoms

Preoperative duration of symptoms significantly correlates with recovery and indicates the importance of early operative intervention to achieve better result. Eight studies [1, 5, 8–12, 16] support this observation, though same number of studies [2–4, 7, 13–15, 17] are against it. The latter observation may be due to either delay in surgery after onset of symptoms causing irreversible cord changes unlikely to affect recovery significantly or due to small sample size causing type 2 error. We had patients operated as early as 1 week to 84 months after onset of symptoms, encompassing a wider range and hence were successful in discovering this correlation. Chang et al. [12] reported a threshold preoperative duration of symptoms of 2 years as having significant influence on recovery, whereas Kuh et al. [14] reported the same as 6 months. However, we do not find any threshold in our study. There is no correlation between preoperative neurological status and duration of symptoms. This may be due to short duration in patients who presented after trauma with severe myelopathy. However, all of them made excellent recovery indicating stronger influence of preoperative duration of symptoms on recovery than preoperative JOA score, proving itself as predictor of outcome.

Preoperative JOA score and individual motor, sensory and bladder scores of JOA

Decreasing JOA score has a negative influence on recovery indicating importance of surgery before developing

Table 8 Pearson's correlation with preoperative neurological status (preoperative JOA score)

Clinical factor	<i>r</i> coefficient	<i>P</i> value	Radiological factor	<i>r</i> coefficient	<i>P</i> value
Age	−0.4687	0.018*	Preop AP diameter	0.2760	0.182
Sex	−0.1294	0.538	Preop transverse diameter	0.2991	0.381
Duration	−0.3538	0.083	Preop canal grade	0.4009	0.047*
Anal sensations	0.6578	<0.001*	Preop DCBR	0.4154	0.039*
Spasticity	−0.4372	0.029*	Presence or absence of cord signal	−0.2917	0.157
Associated trauma	−0.2205	0.289	Signal size	−0.5277	0.007*
Dural adhesions	−0.2693	0.193	Signal type	−0.4094	0.042*
Cervical/lumbar stenosis	−0.3204	0.118	No of segments involved	−0.3165	0.123
			OLF morphology	−0.1562	0.536
			Level of OLF	−0.0373	0.860
			Developmentally narrow canal	0.2856	0.166

Qualitative data were converted to quantitative by numbers as: male, 1; female, 2; anal sensations: absent, 1; present, 2; no trauma, 1; associated trauma, 2; dural adhesion: absent, 1; present, 2; associated cervical/lumbar stenosis: no, 1; decompressed, 2; persistent, 3; intramedullary signal: absent, 1; present, 2; OLF morphology: round-, 1; beak, 2; signal type (T1/T2): absent, 1; normal/high (edema), 2; low/high (cystic), 3; level: T1–T4, 1; T4–T7, 2; T9–L1, 3; developmentally narrow canal: absent, 1; present, 2

* Statistically significant at $P < 0.05$

Table 9 Independent factors associated with preoperative neurological status (preoperative JOA score) with MRA

Factor	Partial regression coefficient (B)	Standardized partial regression coefficient (Beta)	<i>P</i> value
Age	0.08477	0.13986	0.0809
Duration	−0.09131	−0.33657	0.1485
Preop canal grade	−0.08407	−0.27212	0.2136
Signal size	−0.11413	−0.52130	0.0243*
Signal type	−0.91611	−0.34187	0.1168
	13.924 (constant)		

Qualitative data were converted to quantitative by numbers as: signal type (T1/T2): absent, 1; normal/high (edema), 2; low/high (cystic), 3

* Statistically significant at $P < 0.05$

significant functional impairment. Similar observation is made by many investigators [10, 13, 15–17], but most [1–5, 7, 8, 12] do not agree with this finding. JOA score remains most widely used, but some have used Nurick, motor JOA or ASIA scale making it difficult to compare results between them. Nurick and motor JOA does not consider sensory and bladder function, while ASIA scale ignores bladder function.

Progression of preoperative objective sensory deficit negatively influences recovery, while individual motor or bladder involvement was not related to outcome. This may be due to posterior location of sensory tracts resulting in their early involvement due to OLF from posterior aspect. Being a functional scale, motor score of JOA grades only antigravity muscle power, thereby not allowing differentiation of nonambulatory patients, which might prove to be of significant value in statistical comparison. We had only

11 patients with bladder involvement, thereby small sample size not discovering its influence on recovery. No study has compared individual scores with recovery though urinary/fecal incontinence and sensory deficit are reported as negative predictors of outcome [16, 25]. Therefore, we recommend using 'full' JOA scale to evaluate these patients over other scoring systems.

Preoperative spasticity and anal sensations

Neither of them correlates with recovery. Preoperative spasticity is never compared so far with recovery. Though He et al. [16] identify preoperative clonus as having negative impact on recovery, while Shiokawa et al. [11] report that tendon reflexes have no correlation with recovery. Though absent anal sensations is considered as a significant factor leading to poor recovery in trauma setting [31]; we could not find similar effect in myelopathy setting. This may be because very few patients present so late; hence the small sample size makes it difficult to achieve statistical significance. Additionally, gradual progression of myelopathy might allow rare patient to make good recovery [32] after decompression of OLF as seen in one patient making good recovery out of four patients with absent anal sensations. As preoperative neurological status worsens, spasticity significantly increases, and anal sensations are likely to be significantly impaired or absent.

Associated trauma

Asymptomatic thoracic OLF is known to become symptomatic after trauma [32]. Park et al. [32] in a non-statistical survey found that recovery is less in this group of

patients. However, we agree with Hur et al. [15] and Li et al. [33] who reported that trauma has no influence on recovery in a statistical and nonstatistical survey, respectively. Compressive effects of hematoma and edema of spinal cord after traumatic event are likely to regress, resulting in good surgical outcome. Associated trauma has significant negative impact on recovery in cervical myelopathy [34] which may be because of larger influence of dynamic factors and greater range of motion in cervical spine making cervical spinal cord prone to more significant myelopathy following trauma as compared with thoracic myelopathy [10, 35]. Preoperative neurological status does not correlate with traumatic onset of myelopathy, which may be because only two patients presented after trauma in our study.

Associated cervical or lumbar stenosis

Associated cervical and lumbar stenosis has no influence on recovery if decompressed and persistent lesions are not differentiated. However, decompression of associated lesion shows significantly better recovery than persistent ones and even better than OLF alone patients. Though accurate clinical examination can differentiate the clinically symptomatic lesions, the authors believe that close follow-up of these patients is necessary and if they become symptomatic, then either simultaneous or staged decompression is required to achieve better function. Chang et al. [12] found that presence of proximal stenosis is negative predictor of outcome following decompression of subjacent stenosis. They proposed that decompression of OLF in presence of proximal stenosis would lead to caudal movement of CSF into the expanded sac and might decrease CSF buffer at stenotic level, thereby allowing cord compression [36]. Additionally, distal movement of CSF could reduce intrathecal pressure proximally, allowing epidural venous engorgement. This may compromise venous drainage resulting in cord swelling and additional cord compression [36]. He et al. [16] also differentiated between operated and unoperated lesions and found no differences in recovery. Others [11, 14, 17] observed that associated stenosis has no impact on recovery, but they did not differentiate them failing to uncover the finding reported by us. Better recovery is seen in decompressed lesions, though the finding was statistically insignificant; Miyakoshi et al. [10] statistically support same at 1 month after surgery. They cited accelerated neurological progression as the reason for early surgery resulting in better recovery at 1 month, although final recovery was similar to those with OLF alone [10]. Associated stenosis has no influence on preoperative neurological status due to thoracic OLF although associated lumbar stenosis may cause mixed

upper and lower motor neuron findings or may mask upper motor neuron signs in some cases [37].

Dural adhesions

Dural adhesion has no influence on recovery. Two studies [10, 15] reported same, but Miyakoshi et al. [10] found that recovery at 1 month is significantly less in the presence of dural adhesions though final recovery remains unaffected. No attempts at complete removal of OLF should be made when dura is found adherent to avoid dural tear and leaving a floating adherent fragment gives satisfactory results [33]. We found no patient with less than 12 months of duration of symptoms with adhesions, indicating that prolonged compression of dura is necessary to cause adhesion. Miyakoshi et al. [10] reported that the presence of tandem lesions hastens neurological deterioration and therefore early surgery leading to availability of less time for adhesions to develop resulting in lesser incidence of adhesions in patients with tandem lesions. Dural adhesions have no relation with preoperative neurological status.

Preoperative dural canal diameter, canal grade and DCBR

Preoperative AP or transverse dural canal diameter has no correlation with recovery or preoperative neurological status. But as the preoperative canal grade and DCBR decrease, the recovery significantly declines and preoperative neurological status worsens. Diameters are absolute values affected by changes in size and gender, while preoperative canal grade and DCBR being proportionate values remains unaffected, making them best measurements to grade canal stenosis. BCBR is a radiographic measure of size of bony canal in relation to vertebral body size, thereby giving an estimate of developmentally narrow canal. However, with the help of MRI, DCBR gives a measure of size of dural canal or space available for cord as it eliminates space occupied by soft tissue impingements (OLF, disc herniation, etc.) from bony canal.

Being predominantly a static compressive myelopathy [10, 35], preoperative neurological status and recovery correlate with the canal measurements. Although an argument of vascular involvement leading to more severe myelopathy and lesser recovery despite less severe stenosis could be given, a reasonable explanation is that vascular causes are more likely in anteriorly located thoracic OPLL, while OLF being posterior spares anterior circulation [32, 33, 38]. Since we excluded OPLL cases, vascular causes are unlikely to be operating in our series, thereby 'allowing' canal measurements to correlate. Improvement in diameter and canal grade shows no correlation with recovery. Developmentally narrow canal has no impact on

preoperative neurological status but shows significant correlation with younger age at onset of symptoms, and due to plasticity of neurons at younger age it does not affect recovery. Similar finding is noted in patients of cervical myelopathy [39].

Intramedullary signal–presence, size and type

Presence or absence of T2 weighted intramedullary signal is not related to outcome, but whenever present, ISS >15 mm significantly compromises recovery. Most [7, 11, 13–15, 17] agree that presence of intramedullary signal does not decrease recovery, but one study [16] is against this finding. No study has made attempts to find influence of ISS on recovery. Although ISS increases as the number of level affected increases, we also found that even in single segment compression it varies widely and becomes a major factor affecting recovery in this larger group of myelopathy patients. Postoperative decrease in ISS was noted in all patients except one patient who worsened following surgery due to increase in ISS. There is no correlation between decrease in ISS and recovery. Hypointense signal in T1 and hyperintense in T2 indicating cystic changes have negative influence on recovery as compared with normal in T1 and hyperintense in T2 indicating cord edema or inflammation. Hypointense signal in T1 has been shown to have negative impact on recovery in patients of cervical myelopathy [40, 41]. The presence or absence of signal has no correlation with preoperative neurological status, but severity increases as ISS increases or IST changes from edema to cystic variety. No literature is available to compare this finding.

Number of segments involved and level of involvement

Kawaguchi et al. [3] reported OLF affecting more than two segments as predictor of poor outcome, while all other studies [1, 3, 4, 6, 8–10, 13–15] including ours, do not find number of segments as having any impact on recovery. Takei et al. [8] found midthoracic involvement as having negative influence on recovery, while others [4, 6, 8, 11, 12, 15, 16] agree with us as level having no influence on recovery. Preoperative neurological status does not correlate with number or level of OLF.

Morphology of OLF

OLF morphology does not affect recovery or preoperative neurological status. Kuh et al. [14] feel that beak type OLF is very difficult to remove since it compresses like an awl, though they did not find any statistical correlation with recovery. Others [4, 7, 10, 11, 15, 16] have used different classifications making it difficult to compare them.

Predictors of outcome and preoperative neurological status

MRA identified that independent factors responsible for predicting outcome are preoperative duration of symptoms and ISS measured on MRI. With help of this sophisticated test we could formulate an equation to predict RR.

The only factor that can predict preoperative neurological status is ISS, indicating that any pathological change in spinal cord reflects into functional impairment and all other factors act indirectly by effecting changes in the spinal cord.

Out of 17 studies [1–17] reporting factors affecting outcome, only four studies [10, 12, 15, 16] used MRA to identify prognostic factors. Our study is unique due to four reasons:

1. The study evaluates many factors which were never studied so far like, preoperative ISS and IST; preoperative canal diameters, preoperative canal grade and preoperative DCBR; improvement of diameters and canal grade; preoperative spasticity and anal sensations.
2. To our knowledge, this is the largest study of thoracic myelopathy due to OLF reported from India.
3. The authors have made the first attempt to formulate an equation to predict postoperative recovery.
4. This is the first study to investigate factors responsible for preoperative neurological status in thoracic myelopathy due to OLF.

Conclusion

The only factor that determines preoperative neurological status is ISS, indicating that pathological changes in spinal cord play main role in deciding functional impairment. Most important predictors of surgical outcome are preoperative duration of symptoms and preoperative ISS on MRI. The presence or absence of intramedullary signal has no influence on recovery, but whenever present, size >15 mm significantly decreases recovery. Though low preoperative JOA score decreases chances of recovery, it is not a predictor of outcome indicating that even these patients can make good recovery if operated early. The proposed MRE may prove a valuable tool to predict postoperative recovery for thoracic myelopathy due to OLF, although future studies are required to validate this equation before its widespread acceptance is done.

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