INTRODUCTION

Split cord malformation (SCM), characterized by a duplication of the spinal cord, represents an important cause of tethered cord syndrome. Depending on the composition of the intervening septum and the presence or absence of simultaneous duplication of the thecal sac, these malformations are divided into type 1 and 2. Pang revolutionized the thinking of neurosurgeons and embryologists when he proposed the terminology “split cord” instead of the earlier terms “diploymelia” and “diastematomyelia.”[1] Subsequently, Mahapatra and Gupta[2] classified bony spur into four types based on the position of bony spur in relation to cord and its dural sleeves. This classification scheme addressed surgical nuances in a better way, conceptualizing the bony spurs in coronal planes. However, in our surgical experience, we realized that a three-dimensional (3D) orientation of spur is more comprehensive. Understanding of 3D orientation is
essential for better surgical results. This article entails our experience of managing 50 patients of type 1 SCM and their surgical management. The purpose of this study was to highlight surgical importance of 3D assessment of the bony spurs and their correlation with clinical presentation and operative outcome.

**MATERIALS AND METHODS**

**Study design**

For this study, we retrospectively analyzed 50 patients of SCM type I, operated at our center from January 2006 to December 2017. Patients of SCM type II were excluded from study. Patients whose radiological and surgical details were not available at follow-up were also not included. Individual consent along with institutional ethical clearance (IEC 2017-95-MCh-EXP) were obtained for this study. We investigated all patients of SCM type 1 with computed tomography (CT) scans at the level of interest as well as with urodynamic assessment, pertinent to age, irrespective of the urinary symptoms. Ultrasonographic evaluation of vesicourethral reflux or post-voidal residual volume in uroflowmetric study was carried out wherever possible. The demographic profile, level of split, type of lesion, orientation of bony spur in different planes, associated anomalies, operation notes, and postoperative outcomes were recorded from the hospital case files and outpatient follow-up records.

**Radiological assessment**

After craniospinal magnetic resonance imaging (MRI) (T1-weighted image and T2-weighted image coronal, axial, and sagittal views) screening of patients, the bony spurs were analyzed on the basis of multiplanar CT scan. The axial sections were used for defining the spurs into ventral complete, ventral incomplete, and dorsal types [Figure 1]. Ventral bony spur with broad attachment anteriorly and continuation up to the lamina posteriorly was labeled as “complete ventral type,” whereas if the posterior end of spur was not reaching up to lamina then it was labeled as “incomplete ventral spur.” “Dorsal bony spur” had broader attachment posteriorly and did not reach up to the vertebral bodies anteriorly. In the sagittal plane, bony spur was directed either straight (horizontal), upward, or downward. In the coronal plane, bony spurs were one of the four types (type 1a, 1b, 1c, and 1d) as described by Mahapatra and Gupta.[2] Patients in our study had both simple SCM type 1, wherein no other congenital dysraphic anomaly was reported, as well as complex SCM type 1. The latter included patients with coexistent

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**Figure 1:** Ventral complete, ventral incomplete, and dorsal type of spurs in axial plane
lipomyelomeningocele (LPMC), myelomeningocele (MMC), or congenital dysraphism-related tumors such as lipoma or teratoma. Both CT scan and MRI were carried out simultaneously to subdivide the spurs as some spurs that appear incomplete in an axial cut may have complete diagonal course.

**Outcome assessment**

The postoperative complications were considered as minor or major. New-onset neurological deficits, major wound problems such as cerebrospinal fluid (CSF) leak, and reexploration were considered as major postoperative complications. Minor complications were any wound infection not amounting to additional antibiotics or hospital stay or any sensory deficit in immediate postoperative period, which improved at the time of discharge.

Patients who maintained their preoperative status or showed improvement in any of the preoperative symptoms were considered as having “satisfactory outcome,” whereas any new-onset neurological deficit or any major postoperative complication was considered as “unsatisfactory outcome.”

**RESULTS**

**Demographical and clinical profile**

Of 440 cases of spinal dysraphism operated at our center from January 2006 to December 2017, SCM accounted for nearly one-fifth of them (*n* = 94, 21.36%). Among them, 50 patients of type 1 SCM with relevant details available were included for this study (67.5%).

The mean age of clinical presentation was 83.5 months (range: 1 month–25 years; median = 60 months), 74% of the patients being in the less than 10 years of age. Twenty-four (48%) patients were male and 26 (52%) were female [Table 1].

Difficulty in walking was the most common presenting complaint (70%; *n* = 35), followed by cutaneous stigmata of presence of tuft of hair on the back in 30% patients (*n* = 15). A total of 8 (16%) patients presented with nonhealing ulcers in the foot and 10 (20%) patients complained of bladder dysfunction. Twelve (24%) patients had normal neurological examination (tuft of hair [*n* = 4], swelling at back [*n* = 5], foot ulcer [*n* = 2], and dermal sinus tract [*n* = 1]).

Among the other congenital associations, three patients had Chiari malformation type II and one patient had absence of the lower ribs. Ten (20%) patients had associated foot deformity and 22% (*n* = 11) patients had spinal curvature anomaly.

**Subgroups with different orientation of bony spur**

Twenty-four (48%) patients had ventral complete type spur, 19 (38%) had ventral incomplete type, and

| Table 1: Demographic profile of patients included in our study (*n* = 50) |
|-----------------------------|-----------------------------|
| **Demographic profile of patients** | **Number of patients / percentage** |
| **Age** | Mean = 83.58 months (median = 60 months, SD = 80.377, range: 1–300 months) |
| **Gender** | Males = 24 (48.0%) |
| **Clinical features** | |
| Tuft of hairs | *n* = 15 (30%) |
| Motor symptoms | *n* = 35 (70%) |
| Sensory symptoms | *n* = 15 (30%) |
| Bladder symptoms | *n* = 10 (20%) |
| Trophic foot ulcer | *n* = 8 (16%) |
| Chiari malformation type II | *n* = 3 (6%) |
| Dermal sinus | *n* = 5 (10%) |
| **Associations** | |
| CTEV | *n* = 10 (20%) |
| Kyphoscoliosis | *n* = 11 (22%) |
| Chiari malformation type II | *n* = 3 (6%) |
| **Level of conus** | |
| Normally lying above L3 | *n* = 9 (18%) |
| L3 to S1 | *n* = 37 (74%) |
| At or below S1 | *n* = 4 (8%) |
| **Complex spinal dysraphism** | |
| SCM with LPMC | *n* = 7 (14%) |
| SCM with MMC | *n* = 10 (20%) |
| SCM with other dysraphism | *n* = 4 (8%) |
| **Postoperative outcome** | |
| Wound-related complications | *n* = 11 (22%) |
| Deterioration in neurological state | *n* = 1 (motor deterioration) |
| Improvement | *n* = 18 (36%) |
| Same neurological status as preoperative | *n* = 18 (36%) |
| Satisfactory | *n* = 46 |
| **Follow-up** | |
| Improvement | *n* = 38 |

7 (14%) had dorsal bony spur [Table 2]. On coronal section, 25 (50%) were type 1a SCM, 13 (26%) were type 1b, 3 (6%) were type 1c, and 9 were type 1d SCM. A total of 36 (72%) patients had horizontally directed spur, 6 had spur directed upward, whereas 6 had downward directed spur. On comparison among these, no significant association was found in terms of clinical presentations, surgical difficulties, and outcomes [Table 3].

Patients with dorsal bony spurs presented with a high incidence of motor symptoms (71.4%), the ventral incomplete type of bony spur was predominantly associated with sensory symptoms (42.1%), whereas bladder disturbances were present in 28.5% of patients in the dorsal bony spur group. Moreover, the dorsal
spur group had a 28.6% incidence of scoliotic deformity. Foot deformity was more commonly associated with ventral types (21% in both ventral complete and ventrally incomplete). As far as the surgical results were concerned, the patients with dorsal bony spurs [Table 4] showed better outcomes (85.7%) when compared to their ventral counterparts.

Most common site for bony spur was lumbar region (48%) followed by dorsolumbar junction (34%). In lumbar, ventral complete as well as incomplete types were almost equally distributed, whereas at dorsolumbar junction level, the ventral complete subset was more common (58.8%). The dorsal bony spurs had predisposition for the lumbar spine ($n = 3/7$).

**Complex SCM**

Overall, there were 7 (14%) patients of SCM with associated LPMC and 10 (20%) patients with associated MMC. Three (6%) patients had associated intramedullary teratoma and one had dorsal myeloschisis. Complex SCM with MMC had an early age of presentation (median = 12 months) when compared to the simple SCMs (median = 60 months; $P = 0.06, 95\%$ confidence interval [CI]: 50.9–104.04).

A high incidence of low-lying tethered cord was observed in our study. A total of 30/50 (60%) patients had low-lying cord with SCM. Of these 30 patients, 18 had SCM simplex, whereas the remaining had complex SCM.

**Postoperative outcome**

At the time of discharge, 36% of cases ($n = 18$) had improvement in clinical symptoms, whereas 28 patients remained in the same preoperative neurological status. Only one patient had neurological deterioration in our study. In total, 11 (22%) patients had wound-related complications in the postoperative period. Of these, eight had minor CSF leak, which was managed on daily dressing and did not require any extra hospital stay. One patient required CSF diversion in the form of ventriculoperitoneal shunt along with wound repair. Two patients required resuturing, which delayed their discharge from the hospital. Therefore, 46 of our patients were discharged in a favorable state, whereas the outcome at the time of discharge was unfavorable in four patients (one motor deterioration and three with protracted wound complications).

**Table 2: Distribution of bony spur according to orientation in multiplanar CT scan**

| Axial orientation of bony spur | Number of patients / percentage |
|-------------------------------|-------------------------------|
| Ventral complete type         | $n = 24 (48\%)$               |
| Ventral incomplete type       | $n = 19 (38\%)$               |
| Dorsal type                   | $n = 07 (14\%)$               |
| Coronal orientation of bony spur |                             |
| Type 1a                       | $n = 25 (50\%)$               |
| Type 1b                       | $n = 13 (26\%)$               |
| Type 1c                       | $n = 3 (6\%)$                 |
| Type 1d                       | $n = 9 (18\%)$                |
| Sagittal orientation of bony spur |                             |
| Straight horizontally directed | $n = 36 (72\%)$               |
| Directed upward from base     | $n = 6 (12\%)$                |
| Downward directed from base   | $n = 6 (12\%)$                |

**Table 3: Analysis of clinical symptoms and surgical outcome in complex SCM and different types of bony spurs**

| Clinical parameters | Ventral complete type bony spur ($n = 24$) | Ventral incomplete type bony spur ($n = 19$) | Dorsal type bony spur ($n = 7$) | Complex SCM ($n = 21$) |
|---------------------|--------------------------------------------|--------------------------------------------|--------------------------------|------------------------|
| Motor               | 17 (70.8%)                                 | 13 (68.4%)                                 | 5 (71.4%)                      | 14/21 (66.67%) as compared to 72.4% in simple |
| Sensory             | 7 (29.17%)                                 | 8 (42.1%)                                  | None                          | 8/21 (38%) compared to 24.13% in simple         |
| Bladder             | 4 (16.67%)                                 | 5 (26.31%)                                 | 2 (28.5%)                      | 5/21 (23.8%) compared to 20.7% in simple       |
| Scoliosis           | 6 (25%)                                    | 3 (15.78%)                                 | 2 (28.6%)                      | 2/21 (9.5%) compared to 31% in simplex         |
| Improvement in follow-up | 78.3%                                    | 77.8%                                      | 85.7%                          | 14/20 (70%) compared to 85.7% in simple        |
Among the four patients who had an unfavorable postoperative outcome at the time of discharge, all had ventral spurs, majority (n = 3) had complex SCM, and the patient with postoperative motor worsening had preexisting motor weakness at ankle and toes.

At follow-up (mean = 60.92 months, 95% CI: 51.35–70.49), majority (n = 20) of the patients went on to show improvement in their symptoms. All of these patients maintained their preoperative status after surgery. One patient (of the three patients with wound complication in the postoperative period) showed symptomatic worsening because of re-tethering and required a resurgery after 10 months. Two patients died of unrelated cause.

**Discussion**

**Patho-embryological insights**

The embryological basis of SCM is still controversial but unified theory by Pang et al.\[1\] is overall acceptable. In their unified theory, Pang et al.\[1\] stated that all types of SCM originate from one basic ontogenetic error. In normal embryological development, the neurenteric canal, connecting the yolk sac and amnion, forms and subsequently closes. An accessory neurenteric canal formed during gastrulation and the pathological persistence of this canal can cause splitting of the notochord and the overlying neural plate, thereby giving rise to an SCM. The mesenchymal cells induce the formation of an osseocartilaginous septum and thereby dividing the spinal canal into two dural sheaths that have separate hemicords. In addition to aforementioned theory, Mahapatra’s theory and McLone’s unified theory explained the occurrence of rare dorsal varieties and complex SCM. We also believe that certain error in embryogenesis at the initial time of neurulation leads to multiple phenotypes. McLone and Knepper\[3\] proposed that defect in stage disjunction can lead to abnormal proliferation of mesenchyme and tethering at that level. Abnormal failure of fusion or failure of neuropore to close at multiple levels remains the best probable explanation of multiplicity.\[4\]

The embryological details of dorsal bony spur are controversial [Table 4]. It is believed that some abnormal cells migrate posteriorly and get attached to posterior elements losing contact with ventral structures.\[5\] Another possibility is that these abnormal cells pass around the hemicords circumferentially and may enter in between hemicords from dorsal side.\[6\] Although the exact mechanism is still to be defined, we found that most of our patients had posterior element hypertrophy or fusion. Some had missing bony parts posteriorly. So it may be possible that during their genesis, the posterior bony elements gave rise to the abnormal bony proliferation.\[5,7,8\]

**Three-dimensional orientation of bony spur**

Mahapatra and Gupta\[2\] had classified bony spurs into four types (in coronal plane) taking into account the space available between the dura and the bony spur.\[9\] We further observed that the bony spurs can be ventral complete, ventral incomplete, or dorsal types in axial plane. The spurs are usually not straight and have varying width from base to apex [Figure 2]. We believe that knowing these details may improve the surgical outcome of patients as the direction of drilling is the key in dealing with these spurs comprehensively. It also facilitates safe dissection and separation of dural sheath, thus minimizing the chances of dural or cord injury.

Another unique observation of this study was that the ventral spurs were sometimes complete, that is, they fused with the posterior elements and sometimes they fell short or continued as a fibrous component. These spurs seem to be in different stages of differentiation of osteofibrous spur.

A total of 70.8% of patients with complete ventral bony spur presented with motor symptoms, whereas patients with incomplete ventral spur usually presented with sensory loss, numbness, or trophic ulcers. These patients have more propensity for bladder symptoms when compared to their complete counterpart. Previous studies have not classified their results on

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**Table 4: Patients of dorsal bony spur in our study (n = 7)**

| S no. | Age in months | Sex | Level | Associations | Complex | Postoperative course |
|-------|---------------|-----|-------|--------------|---------|---------------------|
| 1     | 60            | M   | L2-L3 | Hydrocephalus for which ETV done earlier | LPMC | Improved            |
| 2     | 156           | F   | L3   |              | LPMC | Improved            |
| 3     | 12            | F   | D12-L1 | D8 hemivertebrae, CTEV, scoliosis | NO | Same               |
| 4     | 84            | F   | D4-5 | D10 hemivertebrae, scoliosis | NO | Improved            |
| 5     | 12            | F   | D4-D6 | Dermal sinus tract | NO | Wound infection     |
| 6     | 36            | M   | L2   | Hydrocephalus for which ETV done earlier | NO | Same               |
| 7     | 36            | M   | D9   |              | NO | Improved            |

CTEV = congenital talipes equino varus, ETV = endoscopic third ventriculostomy, F = female, M = male, NO = not present
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aforementioned basis, hence larger sample size is needed for better conclusion. We believe that complete persistence of accessory neurenteric canal is more often associated with anomalies in gray horn of spinal cord, leading to motor symptoms. Another logical reason for this difference could be that more patients with “low lying cord” were present in complete ventral type than in incomplete ventral type.

We also found that curvature anomaly was more often associated with complete type rather than incomplete type. These findings show that complete bony spur shows more compensated form of embryological error.

Dorsal bony spurs

Some atypical findings were reported in our study. A total of 71.4% of patients with dorsal spurs present with motor symptoms, whereas 42.1% of patients with ventral incomplete type presented with sensory symptoms. These findings were contradictory to general belief. Understanding the nature of disease, that is, congenital rather than a compressive pathology may explain these observations. It is possible that progressive tethering with age at the level of bony spur or high incidence of low-lying cord in our study could be confounding. Two patients showed mild paraparesis in the previous series of four patients.[6] Patients with dorsal bony spurs show better clinical outcome (85.7%) when compared to their ventral counterparts. The dorsal spurs have higher incidence of scoliosis deformity (28.6%). In the series from the study by Prasad et al.[8] also, two patients of the four had scoliosis.

Complex SCMs

Kumar et al. defined complex SCM as the ones associated with other dysraphic states.[10] As we saw, these associations affected the clinical presentation. Patients of SCM with MMC presented at earlier age as compared to other patients. On the contrary, patients of SCM with LPMC/dysraphic tumors presented late. Other studies have also substantiated this finding.[4] This may be because the size of swelling is smaller in LPMC than that in MMC and usually ignored until the patient becomes symptomatic for motor weakness or bladder bowel involvement. We also saw that the incidence of wound complication was rather high with these associated anomalies. The presence of associated MMC or LPMC with SCM demands management of both entities to circumvent its deleterious effect on the developing cord.[15] Pang et al.[1] and Erşahim et al.[11] have also pointed on high incidence of type 1 SCM as an association with MMC. Unusual manifestations such as unilateral paresis or skin lesions should point toward low threshold for screening.[12] Iskandar et al.[13] also highlighted similar fact on the importance of screening of patients with MMC, especially if presented with hypertrichosis.

Associated anomalies

Our series showed 22% association of scoliosis with SCM. McMaster[14] postulated that SCM type 1 was the most common anomaly in patients with scoliosis. Scoliosis is usually seen in 30%–60% of patients with SCM in his series. In our experience, we found that the presence of SCM can lead to progressive curvature changes. Although the sample size was small, there was a trend suggesting that scoliosis was more commonly associated with ventral variety (25% in ventral complete and 15.7% in ventral incomplete). None of the patients below 1 year of age had scoliosis. Feng et al.[13] in their series of 266 patients also quoted 22% association of congenital scoliosis with SCM. Authors have noted that complete addressal of the tethering pathology can lead to stabilization of the scoliotic curvature in many patients avoiding the need for an extensive corrective surgery.

Surgical nuances based on individual morbid anatomy

We prefer high-speed diamond microdrill or rarely ronger upcut no. 1 in cases of neonates. The 3D
understanding of bony spur preoperatively helps greatly in successful drilling of bony spur without cord or dural injury. The technique of drilling the spur differs based on the CT scan showing orientation of spur. The direction and orientation of spur in sagittal plane should be considered and drilling should be carried out accordingly [Figure 2]. Drilling once started should project in cranial direction. If we drill straight, one may land up in dura tear, CSF leak, or cord injury. In ventral complete spurs, the broad base is toward vertebral body. Laminectomy should be done laterally first, leaving middle part (that is attached to spur). Thereafter, the middle attached part of lamina is drilled along with bony spur. The small-sized diamond drill should be used and directed according to the orientation of spur till complete attachment is drilled. When the initial part of spur is drilled, dural margins start falling into view [Figure 3]. But direction should proceed further because dural reflection will be away as spur broadens anteriorly. We can retract the dural tube with the help of microdissector as spinal canal is usually wide at the level of spur. Once vertebral body is reached, the feeling of change in the consistency of bone is felt and dura is reflected on either side and then the base of spur is drilled. In case of ventral incomplete spurs, laminectomy is easy as spur is not attached to lamina but initial part of drilling is tricky. There will be dural folds bulging in view and once the dural tube is retracted, bony spur is seen. In this subset, knowing the orientation of the bony spur in 3D guides us about the direction of drilling. The drilling further advances similar to ventral complete types.

Nuances in dealing with complex SCM and multilevel tethering

The situation becomes further difficult in cases of complex SCM [Figure 4]. The two pathologies can be at same vertebral level or at different levels. In cases where bony spur and second tethering pathology are at different levels, the bony spur is dealt as described earlier. In few cases where both bony spur and other dysraphic pathology occur at same level, the surgical planning and drilling differs. In these subsets, the sac is usually attached to one of the neural elements and identifying the point of attachment is the catch. Once placode is separated and the point of attachment is identified, spur should be drilled easily as described earlier. In cases of complete ventral type, the tip of spur...
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is identified and drilled anteriorly, but our series shows that complex variety is more commonly associated with incomplete type of spur. In this type, we prefer to open placode and another dural sac followed by the excision of fatty elements or sac. Once decompression is complete, the adhesions or bands should be carefully cut to minimize traction to cord. After this, the posterior adequate space is to be ensured and then drilling should be started. After the bone is drilled, dura is opened and two sacs are converted into one tube after sacrificing the nonfunctional medial roots.

It is imperative that the proximal split cord is addressed before releasing the filum terminale to avoid spinal cord injury at the level of the split. Herein lies the importance of whole spine screening MRI in these patients.

We believe meticulous closure is important in SCM surgeries as it contributes to the morbidity and hospital stay. Sharp, meticulous tissue dissection with minimal tissue handling and use of small diameter drill form the important pillars for better outcome. We recommend layerwise closure and prone/lateral positioning of child in 2–3 post-op days.

The limitations of our study were its small size and retrospective design. Perhaps a very stringent exclusion criterion was the underlying reason for the same. Retrospective nature of the study precluded a holistic and prospective analysis of this complex problem. However, this study provides certain new insights into the implications of the bony spur and particularly the surgical nuances involved in their management. As we proposed in this article, a large prospective study comprehensively categorizing the bony spurs will help in determining the actual surgical significance of the points we have raised.

CONCLUSION

The embryogenesis of SCM is still ambiguous, and dorsal spurs may not be as uncommon as previously thought. A thorough preoperative clinico-radiological evaluation, including the 3D assessment of the bony spur as well as the associated dysraphic states, is mandatory before undertaking surgery in these patients. One has to conceptualize the orientation of bony spur in 3D space for better drilling of spur without dural tear or cord damage [Figures 5 and 6]. Wound-related problems and cord re-tethering are the major postoperative concerns with these anomalies. Complex SCM represents a specific surgical challenge.

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Conflicts of interest

There are no conflicts of interest.

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