Posterior-only surgical correction with heavy halo-femoral traction for the treatment of rigid congenital scoliosis associated with split cord malformation

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Abstract

Background: Whether or not, prophylactic neurosurgical interventions of split cord malformation (SCM) before undertaking corrective surgery was the focus of debate. The present study was performed to evaluate the safety and efficacy of posterior-only surgical correction with heavy halo-femoral traction for the treatment of rigid congenital scoliosis (RCS) associated with SCM.

Methods: From 2011 to 2017, 24 patients suffered from RCS associated with SCM underwent posterior-only surgical correction with heavy halo-femoral traction. The apex of the deformity was lumbar (n = 9), thoracic (n = 11), and thoracolumbar (n = 4). There were 13 cases of failure of segmentation; 4 cases of failure of formation and 7 cases of mixed defects. Based on SCM classification, there were 14 patients with SCM type 1 and 10 patients with SCM type 2. The Scoliosis Research Society (SRS)-22 and modified Japanese Orthopaedic Association (mJOA) scores were assessed preoperatively and at the final follow up.

Results: The mean duration of surgery was 327.08 ± 43.99 min and the mean blood loss was 1303.33 ± 526.86 ml. The mean follow-up period was 20.75 ± 8.29 months. The preoperative mean coronal Cobb angle was 80.38° ± 13.55°; on the bending radiograph of the convex side, the mean Cobb angle was 68.91° ± 15.48°; the mean flexibility was 15.04% ± 7.11%. After heavy halo-femoral traction, the mean coronal Cobb angle was reduced to 56.89° ± 13.39°. After posterior-only surgical correction, postoperative mean coronal Cobb angle was further reduced to 32.54° ±11.33°. The postoperative mean correction rate was 60.51% ± 7.79%. At the final follow up, the corrective loss rate of Cobb angle was only 3.17%. The SRS-22 total score improved at the final follow-up evaluation compared with the preoperative SRS-22 total score. The spinal cord function was stable and there were no new neurological symptoms after correction. There were no significant differences between final follow-up and preoperative mJOA total scores.

Conclusions: Without prophylactic neurosurgical intervention and spine-shortening osteotomy, posterior-only surgical correction with heavy halo-femoral traction could be safe and effective for the treatment of RCS associated with SCM.

Keywords: Split cord malformation, Halo-femoral traction, Posterior-only, Rigid congenital scoliosis
Background
Split cord malformation (SCM) is a rare type of congenital spinal cord abnormality however, it might be a common finding associated with congenital scoliosis (CS). Pang’s new nomenclature was established to avoid confusion between diplomyelia and diastematomyelia. In Type I SCM, the spinal cord is divided into two halves with two different dural sleeves by a fibrocartilaginous or bony spur. In Type II SCM, there is only a common intradural fibrous band and dural sac without bony spur [1, 2]. The treatment of CS associated with SCM is complex, and the spinal cord abnormality and spinal deformity must be taken into account. Prophylactic neurosurgical intervention of SCM before undertaking corrective surgery is the focus of debate in spine surgery and neurosurgery [3–5]. Conventional approach for management of CS associated with SCM was first to perform neurosurgical intervention for SCM and then to perform correction of scoliosis 3 to 6 months later. To date, there are no studies concerning the application of posterior-only surgical correction with heavy halo-femoral traction for the treatment of rigid congenital scoliosis (RCS) associated with SCM in the absence of prophylactic neurosurgical intervention and spine-shortening osteotomy. Therefore, the present study was performed to evaluate the safety and efficacy of posterior-only surgical correction with heavy halo-femoral traction for the treatment of RCS associated with SCM retrospectively.

Methods
General data
From 2011 to 2017, 24 patients (9 males and 15 females; age, 10–24 years; average age, 16.38 ± 4.56 years), suffered from RCS associated with SCM, were treated at our Department. In all patients X-ray, CT and MRI examinations revealed: the apex of the deformity was lumbar (n = 9), thoracic (n = 11), and thoracolumbar (n = 4); based on CS classification, all patients were divided into 3 types, including 13 cases of failure of segmentation, 4 cases of failure of formation, and 7 cases of mixed defects; based on SCM classification, all patients were divided into 2 types, including 14 cases of SCM type 1 and 10 cases of SCM type 2; only 7 patients had complication of syringomyelia. Thorough neurological examination, including muscle strength, sensation, pathological and physiological reflexes, was carried out in all of the patients. No apparent neurologic dysfunction was found before surgery. Only 1 patient complained of irregular urination, and thus underwent additional neural electromyography and urodynamic test. Based on all normal results of tests, this patient was also included in this study. The Ethics Committee of Xiangya Hospital of Central South University approved the study. All methods were performed in accordance with the relevant guidelines and regulations. Informed consent for study participation was obtained.

The indications for posterior-only surgical correction with heavy halo-femoral traction were based on the following criteria; (1) the patients suffered from CS associated with SCM; (2) coronal Cobb angle more than 60°; (3) the flexibility less than 30%; (4) consideration of the progression of the scoliosis.

Excluded criteria were based on; (1) SCM-related neurological symptoms were found before surgery, or neurological symptoms occurred during heavy halo-femoral traction; (2) complications with other complex intraspinal anomalies, including tethered cord, tumours, etc.; (3) short and sharp angular kyphoscoliosis, which required a osteotomy; (4) the patients that underwent any types of prophylactic neurosurgical intervention of SCM before.

Preoperative traction
All patients underwent continuous preoperative heavy halo-femoral traction. The initial traction force applied from halo was 2 kg to the head and 2 kg through distal femur traction to their lower extremity. Every day, 2 kg traction force increased to the head and extremity respectively, if patients well tolerated. The maximum traction force could be 33 to 50% of the whole-body weight depending on patient’s tolerance. Neurological function was observed carefully during traction. The traction was applied for 18–20 h per day. The length of the traction period was mainly determined by the radiographic evidence of curve improvement on weekly radiographs. Traction continued till there was no significant improvement in Cobb angle on weekly radiographs [6, 7].

Operative procedure
During the operation, heavy halo-femoral traction was maintained (Fig. 1), and somatosensory evoked potential (SEP) and motor evoked potential (MEP) were thoroughly utilized to monitor the spinal cord functions. After exposure of posterior spinal components through a midline incision, pedicle screws (or hooks) were placed in the key vertebrae’s and adjacent to them for providing multiple anchor points. Facet joint capsules, intertransverse ligaments and contracture soft tissues at the rigid segments were released completely. Then, distraction, compression, rod rotation, and derotation should be adopted for correction. All structural curves need to be fixed and fused. Allogeneous or autogenous bone grafts could be implanted for fusion [8–10].

Postoperative procedure
After operation, the neurological examination was performed. Postoperatively, the patients were mobilized
early and began to exercise 12 days later while wearing braces. All patients wore braces for an average of six months, and then gradually detached the braces.

**Scoliosis Research Society (SRS)-22 and modified Japanese Orthopaedic association (mJOA) scores**

SRS-22 and mJOA scores were assessed preoperatively and at the final follow up to analyse clinical outcomes and neurological function. The SRS-22 questionnaire mainly included mental health, self-image, pain, and functional activities. Furthermore, bladder function, daily activities, clinical symptoms, and subjective symptoms were assessed by the mJOA score.

**Evaluation of radiography and statistical analysis**

At the preoperative, postoperative, and final follow-up stages, the parameters of radiographs including coronal Cobb angle, flexibility ([preoperative Cobb angle – Cobb angle on the bending radiograph of the convex side]/preoperative Cobb angle), coronal Cobb angle after preoperative traction, correction rate were measured. The data was shown as means ± SD and analysed using SPSS 22.0. Paired t-test was used to compare the parameters preoperatively, postoperatively and at the final follow up. \( P < 0.05 \) indicates statistically significant difference.

**Results**

The mean duration of surgery was 327.08 ± 43.99 min (range, 240–380 min) and the mean blood loss was 1303.33 ± 526.86 ml (range, 640–2100 ml). Thorough neurological examination was carried out in all of the patients after operation and at final follow up. No serious complications such as large vessel injury, spinal cord injury, or nerve injury occurred during operation. Moreover, there were no cases of cerebrospinal fluid leakage, death or deep infection, and none of the cases showed new irreversible neural injury.

The average period of follow up was 20.75 ± 8.29 months (range, 12–36 months). No complications related to instrumentation failure occurred. In one patient, the incisures of instrumentation were at the position higher than normal, which resulted in local pain and skin compression because of thinness.

**Correction**

The preoperative mean coronal Cobb angle was 80.38° ± 13.55° (range, 60°-113°); on the bending radiograph of the convex side, the mean Cobb angle was 68.91° ± 15.48° (range, 44.5°- 98°); the mean flexibility was 15.04 ± 7.11% (range, 5.85–28.66%). After heavy halo-femoral traction, the mean coronal Cobb angle was reduced to 56.89° ± 13.39° (range, 35.6° - 87.5°), which showed statistically significant difference between the preoperative and post-traction data \( (P < 0.05) \). After posterior-only surgical correction, the postoperative mean coronal Cobb angle was further reduced to 32.54° ± 11.33° (range, 19.1° - 56.2°), which showed statistically significant difference between the post-traction and postoperative data \( (P < 0.05) \). The postoperative mean correction rate was 60.51 ± 7.79% (range, 48.19–69.40%). The coronal Cobb angle was 35.03° ±11.22° (range, 19.5° - 57.1°) at the final follow up, which revealed statistically significant difference between post-operative and the final follow-up data \( (P < 0.05) \), while the corrective loss rate of Cobb angle was only 3.17%. The patient’s trunk balance and body figure showed good improvement (Fig. 2) (Table 1).

**SRS-22 score**

SRS-22 scores were assessed preoperatively and at the final follow up. The mental health, self-image, pain, and functional activities scores revealed good improvement at the final follow up (Table 2), especially the mental health and self-image scores \( (P < 0.05) \). At the final follow up, the total score increased from 67.22 ± 5.54 to 84.57 ± 4.71. It revealed significant statistical differences between final follow-up and preoperative scores \( (P < 0.01) \).

**mJOA score**

Neurological function was evaluated by mJOA score. There were no significant differences between final follow-up and preoperative scores \( (p > 0.05) \). At the final follow up, the total score increased from 26 ± 2.2 to 27 ± 1.9. Bladder function, daily activities, clinical symptoms, and subjective symptoms showed no significant differences between final follow-up and preoperative evaluation \( (p = 0.669, p = 0.496, p = 0.942, p = 0.067; Table 3) \).
Discussion

Somites, which vertebrae derived from, enclosed neural tube during embryonic development. Any injury resulting in vertebral deformity during embryonic development may cause neural tube defects. Therefore, CS is usually accompanied by intraspinal anomalies, including SCM, tethered cord, syringomyelia, Arnold Chiari malformation, etc. There may also be multiple intraspinal anomalies at the same time [11, 12]. In fact, CS and SCM usually occurred simultaneously in clinical practice. According to report, SCM was observed in 4.0 to 9.0% of patients with CS. The dorsolumbar and lumbar regions are the most common sites. The clinical symptoms could be summarized as following characteristics: lower extremity weakness, atrophy, and deformity, scoliosis, spinal bifida, skin lesions, sphincter dysfunction [13, 14].

However, most of outpatients with CS accompanied by SCM showed no signs of neurological impairment. Patients often presented with spinal deformity during their first visit to the doctor, and SCM was discovered only by chance in the examination of CT and MRI. Furthermore, the spinal cord and Dural sac may be compressed by a bony or fibrocartilaginous spur of SCM during orthopaedic surgery for CS associated with SCM, which causes neurologic injury postoperatively. The presence of SCM greatly increases the risks of correction in patients with CS.

Regarding CS accompanied by SCM, the main purpose of surgery is not only to correct spinal deformity and prevent progression of deformity, but also to prevent nerve injury. Thus far, the neurosurgical management of a bony or fibrocartilaginous spur of SCM before undertaking corrective surgery and corrective procedures are...
### Table 1: Preoperative, postoperative, and final follow-up measurement data

| Case | Age (years) | Location of the major curve | AV | Period of follow up (months) | CS classification | SCM classification | Duration of surgery (min) | Blood loss (ml) | Pre-OP coronal Cobb (°) | Bending Cobb (°) | Flexibility (%) | After traction Cobb (°) | Post-OP correction rate (%) | Final follow-up Cobb (°) | Final follow-up correction rate (%) |
|------|-------------|-----------------------------|----|-----------------------------|-------------------|--------------------|--------------------------|----------------|------------------------|----------------|----------------|--------------------------|----------------------------|--------------------------|--------------------------------|
| 1    | 11          | L                           | L1/2 | 36                          | Mixed             | Type 2             | 240                      | 640           | 62                     | 45.6           | 26.45          | 38.2                     | 21.4                       | 65.48                    | 22.4                         | 63.87                          |
| 2    | 14          | TL                          | L1   | 18                          | Mixed             | Type 1             | 290                      | 950           | 77                     | 70             | 9.09           | 58                       | 35                         | 54.55                    | 38.5                         | 50                             |
| 3    | 22          | L                            | L2/ L3 | 12                          | failure of formation | Type 2             | 365                      | 1050          | 82.8                   | 73.2           | 11.59          | 61.4                     | 28.3                       | 65.82                    | 30.2                         | 63.53                          |
| 4    | 18          | T                            | T10  | 12                          | failure of segmentation | Type 2             | 350                      | 1600          | 81.2                   | 70             | 13.42          | 64.2                     | 25.5                       | 68.6                     | 32.9                         | 59.48                          |
| 5    | 24          | T                            | T8   | 36                          | failure of segmentation | Type 1             | 380                      | 2050          | 113                    | 98             | 13.27          | 87.5                     | 56.2                       | 50.27                    | 57.1                         | 49.47                          |
| 6    | 22          | T                            | T7   | 36                          | failure of segmentation | Type 1             | 360                      | 1960          | 94                     | 88.5           | 5.85           | 62                       | 48.7                       | 48.19                    | 49.9                         | 46.91                          |
| 7    | 10          | L                            | L3   | 24                          | failure of formation | Type 2             | 269                      | 750           | 60                     | 44.5           | 25.83          | 35.6                     | 19.1                       | 68.17                    | 19.5                         | 67.5                          |
| 8    | 17          | T                            | T9   | 12                          | failure of segmentation | Type 1             | 365                      | 1350          | 86                     | 80             | 6.98           | 66.7                     | 41                         | 52.33                    | 44.6                         | 48.14                          |
| 9    | 16          | T                            | T6   | 18                          | failure of segmentation | Type 1             | 375                      | 2080          | 91                     | 82             | 9.89           | 63                       | 45                         | 50.55                    | 47.8                         | 47.47                          |
| 10   | 15          | TL                           | T12  | 24                          | Mixed             | Type 2             | 290                      | 820           | 67                     | 47.8           | 28.66          | 40                       | 20.5                       | 69.4                     | 23.6                         | 64.78                          |
| 11   | 11          | L                            | L2   | 18                          | failure of segmentation | Type 1             | 350                      | 1405          | 84.4                   | 75.6           | 10.43          | 65.1                     | 34.2                       | 59.48                    | 36.7                         | 56.52                          |
| 12   | 23          | T                            | T7   | 18                          | failure of segmentation | Type 1             | 370                      | 2100          | 105                    | 91.4           | 12.95          | 76.3                     | 49.8                       | 52.57                    | 53.2                         | 49.33                          |
| 13   | 18          | T                            | T6   | 12                          | Mixed             | Type 1             | 360                      | 1865          | 89                     | 82.5           | 7.3            | 64                       | 42.8                       | 51.91                    | 44.2                         | 50.34                          |
| 14   | 10          | L                            | L2   | 24                          | failure of segmentation | Type 2             | 250                      | 790           | 69                     | 51.6           | 25.22          | 38.3                     | 22.4                       | 67.54                    | 24.8                         | 64.06                          |
| 15   | 13          | T                            | T11  | 18                          | failure of formation | Type 1             | 310                      | 998           | 74                     | 66             | 10.81          | 55.2                     | 29                         | 60.81                    | 31.7                         | 57.16                          |
| 16   | 17          | T                            | T9   | 12                          | failure of formation | Type 1             | 340                      | 1130          | 85                     | 76             | 10.59          | 64                       | 42                         | 50.59                    | 43.8                         | 48.47                          |
| 17   | 16          | T                            | T8   | 18                          | failure of segmentation | Type 1             | 370                      | 2020          | 96                     | 85             | 11.46          | 69.4                     | 47.3                       | 50.73                    | 49.4                         | 48.54                          |
| 18   | 15          | L                            | L1/2 | 24                          | Mixed             | Type 2             | 315                      | 710           | 71                     | 58.8           | 17.18          | 46.8                     | 22.5                       | 68.31                    | 25.4                         | 64.23                          |
| 19   | 11          | TL                           | T12/ L1 | 24                          | failure of segmentation | Type 1             | 260                      | 690           | 65                     | 50.8           | 21.85          | 41.9                     | 22.2                       | 65.85                    | 24.3                         | 62.62                          |
| 20   | 18          | L                            | L2   | 12                          | failure of segmentation | Type 1             | 331                      | 1780          | 87.3                   | 74.2           | 15.01          | 65.3                     | 34.2                       | 60.82                    | 36.8                         | 57.85                          |
| 21   | 24          | L                            | L3   | 36                          | Mixed             | Type 2             | 270                      | 815           | 64                     | 45.8           | 28.44          | 36.7                     | 20.3                       | 68.28                    | 23.9                         | 62.66                          |
| 22   | 22          | L                            | L2   | 12                          | failure of formation | Type 1             | 350                      | 1797          | 78.4                   | 66.5           | 15.18          | 55.9                     | 24.1                       | 69.26                    | 26.5                         | 66.2                          |
| 23   | 12          | TL                           | T12  | 24                          | Mixed             | Type 2             | 360                      | 1020          | 75.6                   | 65.2           | 13.76          | 56.1                     | 24.4                       | 67.72                    | 26.2                         | 65.34                          |
| 24   | 14          | T                            | T10/ T11 | 18                          | failure of segmentation | Type 2             | 330                      | 910           | 71.4                   | 64.5           | 9.66           | 53.8                     | 25                         | 64.99                    | 27.4                         | 61.62                          |

Note: AV, apical vertebrae; CS, congenital scoliosis; SCM, split cord malformation; T, thoracic; TL, thoracolumbar; L, lumbar. The postoperative and preoperative data as well as the final follow-up and preoperative data were analyzed using paired t tests. P < 0.05 implies statistically significant difference. † P < 0.05 (postoperative vs. preoperative); ‡ P < 0.05 (final follow-up vs. preoperative).
still controversial. Ayvaz et al. [15] advised that neu-
surgical interventions (spur excision and dural recon-
struction) should be recommended even for neuro-
logically asymptomatic SCM type 1 before the cor-
rective surgery to the CS, whereas patients with SCM
type 2 can be treated safely without a need of neurosurgical intervention. In SCM Type 2, it allows the spinal
cord to move relatively independently in the spinal
canal, because two hemi cords exist in one dural canal
without substantial spur. Therefore, there is no need for
additional canal work.

Some authors [16, 17] advocated that the approach for
management of CS associated with SCM was first to
perform surgery for SCM and then to perform ortho-
paedic surgery for correction of the spinal deformity, ap-
proximately 3 to 6 months later. The aim was to prevent
spinal cord injury during deformity correction and re-
duce the incidence of postoperative complications of
the neural system. However, there are several disadvantages of
staged procedures: (1) Due to less clear anatomic
landmarks, surgically complex exposure, and more blood
loss, the follow-up correction becomes more difficult and
complicated. In addition, at the surgical site, a pre-
formed adhesion and possible retethering could make
complex reconstructive operations such as osteotomy
more difficult. (2) The patients suffer from the risks of
anaesthesia and surgery more than once. (3) The staged
procedures increase the financial and psychological
burden in patients, and prolong hospitalization and
rehabilitation.

In recent years, Hui et al. [18] have reported one-stage
operation was effective and safe for the treatment of CS
and SCM, but resection of bony spur was still recom-
ended. In these cases, the correction rate of main
curve was 54.5% without increasing complications. How-
ever, neurosurgical intervention itself is characterized
with high risk of operation and neurological complica-
tions. For surgical interventions of SCM alone, the risk
of infection, cerebrospinal fluid leakage, and neurological
deterioration after neurological intervention was ap-
proximately 7 to 31% [14, 19]. Therefore, Feng et al. [5]
compared the results of two surgical strategies for the
treatment of SCM type 1 and CS. In the resection of
bony spur (BR) group, the neurological complications,
blood loss, and duration of surgery were significantly
higher than those in the nonresection of bony spur (NR)
group. Moreover, prophylactic neurosurgical interven-
tion before corrective surgery was probably not neces-
sary in patients with stable or intact neurological
function.

Posterior spine-shortening osteotomy has recently
been developed [3, 4]. The correction of the scoliosis is
performed following the osteotomy. The scoliosis is cor-
rected later by shortening and compression in the verte-
tectomy gap, which relieves the longitudinal tension.
Theoretically, it should prevent the spinal cord from
stretch injury. However, the correction of the scoliosis in
the presence of the spinal cord being tensioned by the
bony or fibrocartilaginous spur in SCM still poses sig-
nificant risks. Therefore, one-stage operation including
resection of bony spur and subsequent spine-shortening
osteotomy was recommended for preventing spur-
related complications. Nevertheless, this method pre-
sented new challenges, such as more frequent neuro-
logical complications, high level of technical
requirements, difficult operation, blood loss, and opera-
tion time at a single operation. Furthermore, neurosur-
ical interventions (spur excision and Dural recon-
struction) were still performed at the same time, and
there were neurosurgical complications related to
spur.

24 patients, suffered from RCS associated with SCM,
were treated at our Department. No apparent neurologic
dysfunction was found in all patients. All patients under-
went continuous preoperative heavy halo-femoral trac-
tion, with gradual initial traction monitoring the
neurological function carefully; lengthening the spine
step by step. During the surgery, facet joint capsules and
contracture soft tissues were released completely and
widely without spur excision. After posterior-only surgi-
cal correction, the postoperative mean correction rate
was 60.51%. The patients’ body figure and trunk balance

### Table 2 SRS-22 score of preoperative and final follow up

| Parameters                  | Preoperative | Final follow-up | T value | P value |
|-----------------------------|--------------|-----------------|---------|---------|
| Functional activity         | 17.60 ± 2.46  | 20.68 ± 1.53    | -5.208  | 0.000   |
| Pain                        | 20.75 ± 1.94  | 21.98 ± 1.86    | -2.240  | 0.007   |
| Self image                  | 14.77 ± 2.48  | 19.16 ± 2.28    | -6.384  | 0.000   |
| Mental health               | 15.06 ± 2.15  | 19.16 ± 1.92    | -6.368  | 0.000   |
| OP Satisfaction             | –             | 7.94 ± 1.34     | –       | –       |
| SRS-22 total score          | 67.22 ± 5.54  | 84.57 ± 4.71    | -11.689 | 0.000   |

(Note: SRS-22 questionnaires including five aspects: 1. Recovery of functional activities of patients include question 5, 9, 12, 15, 18; 2. Improvement of pain of the patients include question 1, 2, 8, 11, 17; 3. Assessment of self image of the patients include question 4, 6, 2, 14, 19; 4. Assessment of mental health of the patients include question 3, 7, 13, 16, 20; 5. Operation satisfaction was only answered by patients performed operation include question 21, 22)

### Table 3 mJOA score of preoperative and final follow up

| Parameters         | Preoperative | Final follow-up | T value | P value |
|--------------------|--------------|-----------------|---------|---------|
| Subjective symptom | 8.1 ± 1.1    | 9.0 ± 0.6       | -1.980  | 0.067   |
| Clinical symptom   | 6.3 ± 0.2    | 6.3 ± 0.4       | 0.242   | 0.942   |
| Daily activities   | 12.9 ± 1.0   | 13.1 ± 0.9      | -0.686  | 0.496   |
| Bladder function   | -0.4 ± 0.9   | -0.5 ± 0.7      | 0.430   | 0.669   |
| mJOA total score   | 26 ± 2.2     | 27 ± 1.9        | -1.685  | 0.099   |

(Note: Total mJOA-score was 29 including subjective symptom from 0 to 9 score, clinical symptom from 0 to 6 score, daily activities from 0 to 14 score and bladder function from -6 to 0 score)
showed good improvement. This correction rate was higher than that of spine-shortening osteotomy reported by some authors [3, 18], and was similar to that of Chen’s osteotomy [4]. However, the operation time, blood loss, difficulty of operation and incidence of neurological complications were significantly lower than those reported in the literature [4, 18].

Therefore, our findings can be summarized in the following characteristics: (1) With initial skeletal traction gradually, the preoperative traction may increase the tolerance of spinal cord to stretch trees and ischemia from correction of curve. The patient’s neurological status was frequently checked and assessed on preoperative bending and suspension position, and heavy halo-femoral traction, so as to provide a basis for intraoperative orthopaedic procedures, and diminish risks of neurological complications. (2) The preoperative heavy halo-femoral traction may significantly improve curve flexibility and spinal compliance, which allowed for a better overall correction. (3) For neurologically asymptomatic SCM, prophylactic neurosurgical intervention (spur excision and dural reconstruction) itself was characterized by increasing risk of operation and neurological complications. (4) Posterior-only surgical correction with heavy traction was performed to avoid the risks of anaesthesia and surgery more than once, and the disadvantages of spine-shortening osteotomy, such as more operation time, blood loss, difficult operation, high level of technical requirements, and frequent neurological complications. (5) The scoliosis was rigid in all the patients of this study, and the flexibility was only 15.04%. During the surgery, facet joint capsules and contracture soft tissues should be released completely and widely to increase spinal flexibility. (6) Neurological monitoring (SEP and MEP) was the guarantee of the whole operation. (7) If neurological symptoms were found before surgery, or neurological symptoms occurred during heavy traction, our method was not appropriate for these patients, who needed the prophylactic neurosurgical intervention of SCM.

Conclusions
In conclusion, without prophylactic neurosurgical intervention and spine-shortening osteotomy, posterior-only surgical correction with heavy halo-femoral traction could be safe and effective for the treatment of RCS associated with SCM in decreasing the incidence of complications. However, before any procedure, appropriate surgical interventions must be chosen carefully; adequate monitoring during the surgery, preoperative heavy traction and evaluation are necessary to improve clinical results.

Abbreviations
CS: Congenital scoliosis; CT: Computed tomography; MEP: Motor evoked potential; mJOA: Modified Japanese Orthopaedic Association; MRI: Magnetic resonance imaging; RCS: Rigid congenital scoliosis; SCM: Split cord malformation; SEP: Somatosensory evoked potential; SRS: Scoliosis Research Society

Acknowledgements
Not applicable.

Authors’ contributions
AD was involved in study design, data analysis and interpretation, writing the manuscript and critical revision of the manuscript. HQZ was involved in critical revision of the manuscript, statistical expertise and performing most of the analyses presented in the paper. MXT was involved in study conception and design, data collection, development of data collection instruments and critical revision of the manuscript. SHL was involved in data collection, preliminary data analysis and interpretation, critical revision of the manuscript and statistical expertise. QLG was involved in study conception and design, data analysis and interpretation, critical revision of the manuscript. YXW was involved in study conception and design, data analysis and interpretation, writing the manuscript, critical revision of the manuscript, supervision and administrative support. All authors approved the final manuscript.

Funding
The study was supported by the Natural Science Foundation of Hunan Province, China (NO. 2016JJ3160) and key research and development program of Hunan Province, China (NO. 2017SKX062). The funding bodies had no role in the design of the study or in collection, analysis, interpretation or presentation of data.

Availability of data and materials
The datasets analyzed during the current study are not publicly available because a further study about SCM is in progress in our institution, but are available from the corresponding author on reasonable request.

Ethics approval and consent to participate
The Ethics Committee in Xiangya Hospital of Central South University approved the study. All methods were performed in accordance with the relevant guidelines and regulations.

Consent for publication
Written informed consent was acquired from each of the patients (or their parents and legal guardians) to authorize treatment, imageology findings, and photographic documentation. The patients (or their parents and legal guardians) consented to the publication of their pictures as well as their anonymous and clustered data.

Competing interests
The authors declare that they have no competing interests.

Received: 30 June 2019 Accepted: 10 February 2020 Published online: 13 February 2020

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