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Role of MRI evaluation in acute secondary inability to walk in children

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Abstract

Background: Acute bilateral lower limb weakness is a common problem in children which necessitates a rapid method for diagnosis. MRI is a non-invasive imaging technique that produces high-quality images of the internal structure of the brain and spinal cord.

Results: MRI was very helpful in reaching rapid and prompt diagnosis in children with acute inability to walk. Acute disseminated encephalomyelitis (ADEM), Guillain–Barré syndrome (GBS), and acute transverse myelitis (ATM) were the most common causes in our study. MRI proved to be of high sensitivity in detecting the lesions and reaching the diagnosis in ADEM and GBS; however, there was no significant relation between the lesions' size, enhancement pattern, and severity of the disease or prognosis, yet in ATM the site of the lesion and number of cord segment affection were significantly related to the severity of the disease and prognosis.

Conclusion: MRI is a quick tool to reach the diagnosis of children with acute secondary inability to walk, and to eliminate other differential diagnosis which is essential for proper treatment and rapid full recovery. It is highly sensitive in detecting the lesions, their site and size.

Background

Children are commonly brought to the ER with a complaint of acute bilateral lower limbs weakness. A good history and physical examination are of paramount importance in determining etiology. Once a diagnosis is suspected, diagnostic tests should be performed immediately to define the etiology and guide therapy for this emergency situation [1].

The range of potential etiologies include inflammatory, vascular, traumatic, compression of the spinal cord [intradural or extradural], and infectious causes [1].

Guillain–Barré syndrome (GBS) is a common cause of acute flaccid paralysis, characterized by symmetrical weakness of the limbs and hyporeflexia or areflexia. GBS typically occurs after an infectious disease in which the immune response generates antibodies that cross react with gangliosides at nerve membranes [2].

Acute transverse myelitis is a clinical syndrome affecting the spinal cord, which is characterized by acute onset of motor, sensory, and autonomic dysfunction [3].

Acute disseminated encephalomyelitis (ADEM) is a common demyelinating CNS disease in children. Other neuro-inflammatory demyelinating conditions, including multiple sclerosis (MS) which is a demyelinating disorder of the central nervous system, are characterized by multifocal areas of CNS demyelination disseminated in time and space. Para-clinical investigations in MS, including MRI of the brain and spinal cord, serve as useful identifiers of abnormalities consistent with and supportive of MS [4].

The anatomy of the spinal cord and surrounding structures renders the non-invasive imaging methods essential. It is also this anatomical arrangement that creates most of the challenges of imaging the spinal cord [5].

Aim of work

The purpose of this study is to emphasize the value of the MRI in the evaluation of acute secondary inability to

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walk in children and to propose an algorithm for neurodiagnostic guideline in children with acute secondary inability to walk.

Methods

Patients

This study was conducted during the period from July 2017 till July 2018. This study included 30 patients and their age ranged from 1 to 16 years. The patients were referred to an MRI unit from the Children's-Hospital Emergency room and inpatient.

Inclusion criteria

- Patients with acute secondary bilateral lower limb weakness.
- Patient's age between 1 year and less than 16 years old.

Exclusion criteria

1. Patients diagnosed with pseudoparalysis by clinical examination, where the muscle strength is preserved and the motor function is impaired by another mechanism, most often severe pain: e.g., acute viral myositis, pyogenic arthritis-related arthralgia, or bone pain secondary to osteomyelitis, bone fracture, or dislocation.
2. Patients with contraindication to MRI: e.g. Pacemaker, metallic implant, severe claustrophobia, or unstable patient, e.g., mechanical ventilation.
3. Patients with contraindication to contrast: Patients with disturbed renal function test (if creatinine > 2), and patients with glomerular filtration rate (GFR) < 30 ml per min per 1.73 m^2 or any acute renal insufficiency.
   Patients with contrast agent allergy.

Methodology

MRI was performed on Phillips Achieva 1.5-T MRI machine.

Patient preparation before examination

1. Signed consent by parent / guardian.
2. Detailed history taking.
3. Detailed explanation of imaging procedure.
4. Cannula is introduced for contrast injection.
5. Patients are asked to breathe quietly and not to move during the scan (for children > 6 years old).
6. Patients who were unable to stay quiet during the exam were subjected to light oral sedation (for children up to 2 years old), e.g., chloral hydrate (100 mg/kg body weight), if failed, sedation may be used.
7. Before sedation, no clear fluids for 2 h prior to the procedure, no solids for 6 h prior to the procedure.

Positioning for MRI brain

- Head first supine.
- The head is positioned in the 12-channel head coil and immobilized with cushions.

Brain MRI protocol

1. Localizer: A three-plane localizer must be taken in the beginning to localize and plan the sequences, localization starting from the highest point of parietal bone at midline sagittal plane to the base of odontoid process of C2. Localizers were usually less than 25 s. T1-weighted low-resolution scans.
2. Axial T1WI (TR, 450 ms / TE, 12 ms / ST 2:50) spin echo.
3. Axial T2WI (TR, 4540 ms / TE, 96 ms / ST 3:10) spin echo.
4. Axial fluid attenuated inversion recovery (FLAIR) (TR, 9000 ms / TE, 116 ms / TI, 2500 ms / ST 6:50).
5. Sagittal T1WI (TR, 430 ms / TE, 10 ms / ST 3:50) spin echo. 5 mm section thickness and 256 × 256 matrix size.
6. Post-contrast T1-weighted image (in axial, sagittal, and coronal after the administration of IV gadolinium DTPA), the recommended dose of gadolinium is 0.1 mmol/kg (i.e., 0.2 ml/kg in adults, children, and infants), if needed.

Positioning for MRI spine

- Head first supine.
- The torso is positioned in the spine coil and immobilized with cushions.

Spine MRI protocol

1. Localizer: A three-plane localizer must be taken in the beginning to localize and plan the sequences. Localizers were usually less than 25 s. T1-weighted low-resolution scans.
2. Sagittal T1WI (TR, 450 ms / TE, 12 ms / ST 5:50) spin echo.
3. Sagittal T2WI (TR, 4540 ms / TE, 96 ms / ST 4:50) spin echo. 3 mm section thickness and 256 × 256 matrix size.
4. Both axial T1-W and T2-W images were acquired through any abnormality.

5. Post-contrast T1-weighted image (in axial, sagittal, and coronal after the administration of IV gadolinium DTPA), the recommended dose of gadolinium is 0.1 mmol/kg (i.e., 0.2 ml/kg in adults, children, and infants), if needed.

Patient analysis

The patients were categorized clinically according to Hughes classification (a widely accepted scoring system to assess the functional status of patients with neurological disability) (Table. 1) [6], and also patients' bladder affection and sensory loss were assessed. Patients' conscious level is assessed according to Pediatric Glasgow Coma Scale for younger age (Table 2) [7].

Table 2 Pediatric Glasgow Coma Scale [7]

Pediatric Glasgow Coma Scale	Grades
Eye opening	Spontaneous 4 To speech 3 To pain 2 None 1
Best verbal response	Coos, babbles 5 Irritable, cries 4 Cries to pain 3 Moans to pain 2 None 1
Best motor response	Normal spontaneous movement 6 Withdraws to touch 5 Withdraws to pain 4 Abnormal flexion 3 Abnormal extension 2 None 1

Image analysis

For the sake of better characterization of the CNS changes, all the available images were assessed, in addition to the contrast-enhanced MRI images.

In brain studies, MR images were acquired on 1.5-T magnets with slice thicknesses of 5 mm. Each lesion was identified on axial T1/T2/FLAIR images.

When ADEM was suspected, lesions were categorized according to Garg [8]:

- ADEM pattern 1 with small lesions (less than 5 mm).
- ADEM pattern 2 with large or tumefactive lesions with possible perilesional edema and mass effect.
- ADEM pattern 3 with additional symmetric bithalamic involvement.
- ADEM pattern 4 with some evidence of hemorrhage can be identified in the large demyelinating lesions.

The presence or absence of gadolinium enhancement and pattern of enhancement were assessed as homogenous, heterogenous, ring, or patchy enhancement.

To differentiate MS from ADEM in MRI in our study, we relied on the 2010 MacDonald criteria [9] as well as Banwell et. al. [10], as follows: 1 or more non-enhancing T1-hypointense lesions, 2 or more periventricular lesions, absence of a diffuse lesion distribution pattern. Two of these 3 criteria were described to be sensitive for distinguishing MS from ADEM.

For spinal studies, MR images were acquired on 1.5-T magnets with slice thicknesses of 3 mm. T1, T1 post-contrast, and T2-weighted images were reviewed.

Cauda equina nerve roots and conus were assessed for thickening, and nerve root enhancement patterns were categorized according to Yikilmaz et al. [11]: GBS pattern 1 = no enhancement, GBS pattern 2 = anterior nerve roots enhance stronger than the posterior, GBS pattern 3 = anterior and posterior nerve roots enhance equally, GBS pattern 4 = there is contrast enhancement only in the anterior nerve roots.

Spinal cord lesions were reviewed and four main characteristics were assessed:

1. Lesion characterization: T1 signal hypointensity of the spine, signal hyperintensity on T2-weighted images, defined by a signal similar to the CSF.
2. Size of the lesion: whole spinal cord lesion corresponds to a hyper T2 lesion extending from the cervical to the lumbosacral region; a large lesion is defined as 3 or more vertebral segments on MRI longitudinally.
3. Location: cervical (within C1 to C7); thoracic (T1–T12); lumbar (L1–conus).

Table 1 Hughes scale [6]

Grade	Hughes scale
0	Normal neurological status
1	Able to run but with minor signs or symptoms of neuropathy
2	Able to walk 5 m across an open space without assistance, but incapable of manual work
3	Able to walk 5 m across an open space with assistance and incapable of manual work
4	Bed- or chair-bound (unable to walk 5 m with a walker or support)
5	Requires assisted ventilation (for at least part of the day)
6	Death

4. Number of the lesions.

Once patients presented by acute inability to walk guided by the emergency neurological life support [12], patient's airway and breathing is assessed first then patient's detailed history and clinical and neurological examination was obtained. Neurological examination was obtained to localize the site of the pathology whether it was brain, spinal cord, peripheral nerve, or muscular to determine the radiological exam needed to be done.

Statistical analysis

Data were coded and entered using the statistical package for the Social Sciences (SPSS) version 26 (IBM Corp., Armonk, NY, USA). Data was summarized using mean, standard deviation, median, minimum, and maximum in quantitative data and using frequency (count) and relative frequency (percentage) for categorical data. Comparisons between quantitative variables were done using the non-parametric Kruskal-Wallis and Mann-Whitney tests [13]. For comparing categorical data, chi square (χ^2) test was performed. Exact test was used instead when the expected frequency is less than 5 [14]. *P* values less than 0.05 were considered as statistically significant.

Results

Demographic data

The pool of this study is 30 patients, and their ages ranged from 1 to 16 years. The mean age was 6.1. The most affected age was 3. There were 18 (60%) males and 12 (40%) females.

Out of the 30 patients of acute secondary inability to walk, 12 patients (40%) had confirmed diagnosis of acute disseminated encephalomyelitis, 7 patients (23.3%) with GBS, 5 patients (16.7%) with acute transverse myelitis, 3 patients (10%) with multiple, and 3 patients (10%) with other diagnoses such as spinal tumor and cerebrovascular events.

ADEM

ADEM (12 out of 30 patients) was the most common CNS abnormality found. There were 8 males and 4 females, all presented with clinical paralysis of upper motor neuron lesion (UMNL).

Definite diagnosis of those patients was achieved with clinical symptoms suggesting ADEM including encephalopathy, and MRI findings.

MRI findings The lesions demonstrated hyperintense signal on T2W and FLAIR images and iso/hypointense signal T1W in all patients.

All patients showed white matter subcortical region affection, and no patient had gray matter affection. All patients showed bilateral involvement of cerebral areas, seven patients (58.4%) had symmetrical affection and about five patients (41.6%) had asymmetrical involvement.

Subcortical white matter hyperintense T2/ FLAIR lesions were evident in all pediatric patients with ADEM, i.e., in 100% of our patients during their initial brain MRI.

In our study, MRI showed high sensitivity in diagnosis of ADEM (100% sensitivity and 100% negative predictive value (NPV)). However, MRI had about 66% specificity, with 92% positive predictive value (PPV).

All the patients demonstrated MRI pattern as ADEM 1 pattern in six patients (50%) (Fig. 1) and ADEM 2 pattern in six patients (50%) (Fig. 2).

Most frequently affected areas were bilateral fronto-parietal areas in 6 patients (50%), parietal areas were affected in 4 patients (33.3%), and occipito-parietal areas were affected in 2 patients (16.7%).

All patients demonstrated lesion enhancement as patchy pattern (Fig. 3), seven patients (58.3%), and ring pattern (Fig. 4) in five patients (41.7%).

Clinic-pathological correlation with ADEM disease severity The patients with ADEM were divided according to their disability at the time of presentation into 2 groups: group A with 1 or 2 Hughes scale and Glasgow Coma Scale 13 or more, and group B with 3 or 4 Hughes scale and Glasgow Coma Scale 12 or less.

In our study, group A patients, 5 of them (62.5%) showed fronto-parietal involvement, 2 of them (25%) showed occipito-parietal involvement, and one of them (12.5%) showed parietal involvement.

Among group B patients, one of them (25%) showed fronto-parietal involvement and the other three of them (75%) showed parietal involvement.

Patients with ADEM were also evaluated for their bladder affection, among patients with bladder affection, one of them (20%) showed fronto-parietal involvement, 3 of them (60%) showed parietal involvement while one of them (20%) showed occipito-parietal involvement.

Among patients with no bladder affection, three of them (75%) showed fronto-parietal involvement and one of them (25%) showed occipito-parietal involvement.

In our study, there was no significant correlation between the severity of the disease and lesion distribution in MRI (*P* value = 0.120 for Hughes scale and *P* value = 0.377 for bladder affection).

In our study, in group A patients, 4 of them (50%) showed ADEM pattern 1 in MRI while 4 of them (50%) showed ADEM pattern 2 with relatively large lesions.

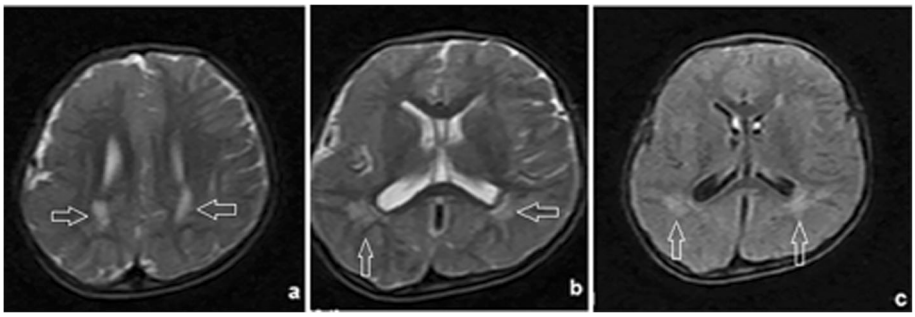

Fig. 1 **a**–**c** MRI brain demonstrates ADEM 1 pattern, axial FLAIR Wi showing small hyperintense fronto-parietal periventricular lesions (arrows)

In group B patients, two of them (50%) showed ADEM pattern 1 while two of them (50%) showed ADEM pattern 2.

Patients with ADEM were also evaluated for their bladder affection, among patients with bladder affection, three of them (60%) showed ADEM 1 pattern while two of them (40%) showed ADEM 2 pattern.

Among patients who showed no bladder affection, one of them (25%) showed ADEM 1 pattern while three of them (75%) showed ADEM 2 pattern.

In our study, there was no significant correlation between the severity of the disease and the pattern of the lesions in MRI (*P* value = 1 for Hughes scale and *P* value = 0.61 for bladder affection).

Among group A, 5 patients (62.5%) showed patchy pattern of enhancement and 3 of them (37.5%) showed ring pattern of enhancement.

Among group B, two patients (50%) showed patchy pattern of enhancement and the other two (50%) showed ring pattern of enhancement.

Among the patients with bladder affection, two (40%) showed patchy pattern of enhancement while three patients (60%) showed ring pattern of enhancement.

Among the patients with no bladder affection, three patients (75%) showed patchy pattern of enhancement while one patient (25%) showed ring pattern of enhancement.

In our study, there was no significant correlation between the severity of the disease and the enhancement pattern of the lesions in MRI (*P* value = 0.639 for Hughes scale and P value = 0. 773 for bladder affection).

Prognosis in ADEM patients Patient with ADEM showed various prognostic sequel 2 weeks after the onset of the disease: complete recovery, walking with aid, and worsening of symptoms which needed ICU admission.

Among patients who showed complete recovery (6 patients), four of them (66.6%) showed fronto-parietal involvement, one patient (16.6%) showed parietal

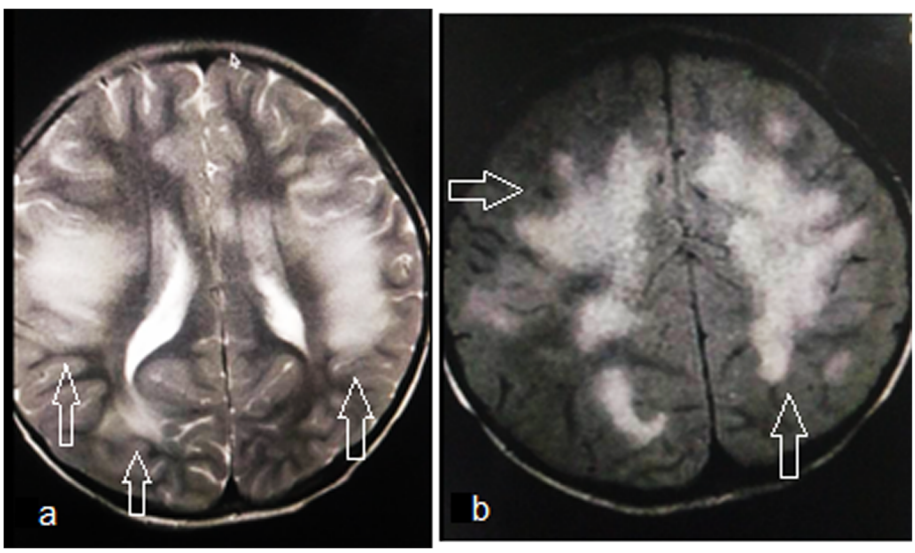

Fig. 2 MRI brain demonstrates ADEM 2 pattern. **a**, **b** Bilateral rather symmetrical fronto-parietal periventricular white matter poorly demarcated patchy areas of abnormal signal high in T2W (**a**) as well as in FLAIR (**b**), impressive of demyelinating lesions

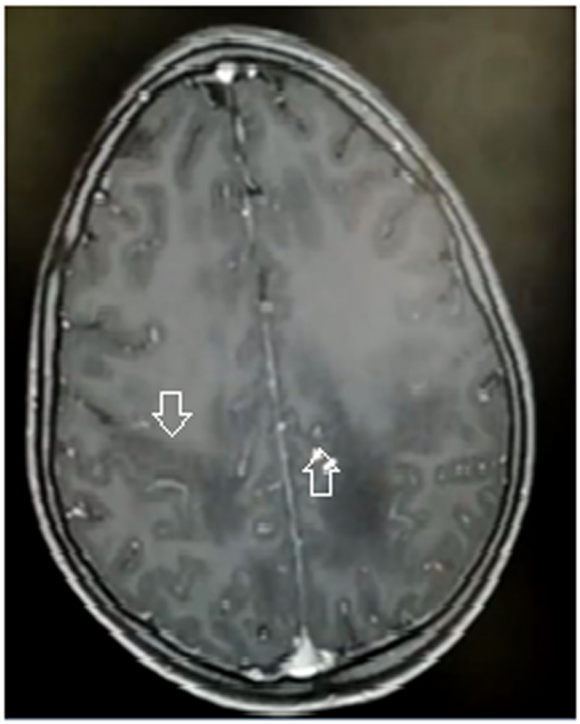

Fig. 3 MRI brain demonstrates ADEM patchy enhancement pattern, axial post-contrast T1WI showing patchy enhancement of bilateral parietal subcortical lesions (arrows)

involvement, and one patient (16.6%) showed ADEM occipito-parietal involvement.

Four of them (66.6%) showed ADEM pattern 1 and two patients (33.3%) of them show ADEM pattern 2.

Four of these patients (66.6%) showed patchy pattern of enhancement and two of them (33.3%) showed ring pattern of enhancement.

Among the two patients who developed walking with aid after 2 weeks, one showed fronto-parietal and the other showed parietal involvement, both showed ADEM 2 pattern, one showed patchy enhancement and the other showed ring enhancement.

Among patients who showed worsening of their symptoms and needed ICU admission (4 patients), one patient (25%) showed fronto-parietal involvement, two patients (50%) showed parietal involvement, and one patient (25%) showed occipito-parietal involvement.

Two of those patients (50%) have ADEM 1, two patients (50%) ADEM 2 pattern. Two patients (50%) showed patchy enhancement and the other two (50%) showed ring enhancement.

In our study the lesion size, distribution and enhancement pattern did not correlate with the prognosis (*P* value = 0.740 for lesion size, *P* value = 0.740 for enhancement pattern and *P* value = 0.610 for the affected areas).

GBS

We had seven patients with GBS, five males and two females, all with lower motor neuron (LMN) paralysis.

Definite diagnosis of those patients was achieved by clinical symptoms including acute lower limb ascending paralysis, electrodiagnosis, and MRI findings.

MRI findings All patients demonstrated thickened cauda equina nerve roots with post-contrast T1W enhancing nerve roots. All the patients demonstrated nerve root enhancement pattern as GBS 2 pattern, 4 patients (57%) (Fig. 5), and GBS 3 pattern, 3 patients (43%) (Fig. 6).

MRI proved to be very sensitive and specific in diagnosis of GBS; nerve root enhancement was evident in all patients with GBS, i.e., in 100% of our patients during their initial spinal magnetic resonance imaging.

In our study, MRI showed high sensitivity and specificity in diagnosis of GBS (100% sensitivity, 100% NPV, and specificity 100%, with 100% PPV), and larger sample size would be of value for more accurate results.

Clinico-pathological correlation with GBS The patients with GBS are divided according to their neurological signs at the time of presentation into 2 groups: group A with 1 or 2 Hughes scale and group B with 3 or 4 Hughes scale.

Among group A patients, two of them (50%) showed GBS pattern 2 while two of them (50%) showed GBS pattern 3 enhancement.

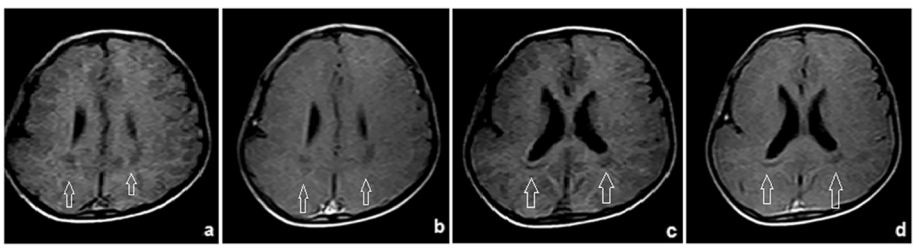

Fig. 4 a–d MRI brain demonstrates ADEM ring enhancement pattern, axial post-contrast T1WI showing ring enhancement of bilateral parietal subcortical lesions (arrows)

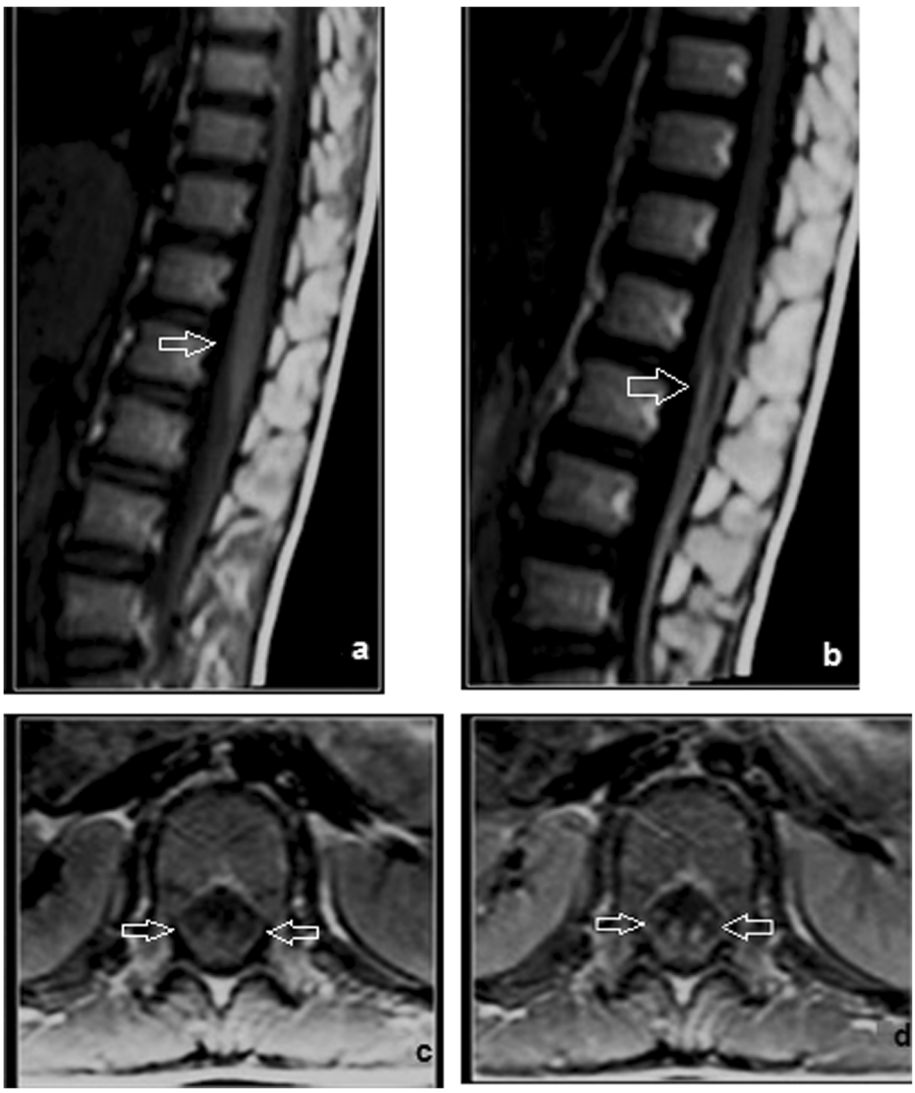

Fig. 5 MRI demonstrates **a**, **c** sagittal and axial T1W show mildly thickened cauda equina nerve roots. **b**, **d** Sagittal and axial post-contrast T1W show anterior and posterior nerve roots of the cauda equina which is predominant anteriorly, pattern 2 of contrast enhancement

Among group B patients, two of them (66.6%) showed GBD pattern 2 while one patient (33.3%) showed GBD pattern 3.

In patient with GBS who showed bladder affection, three of them (75%) showed GBS 2 pattern while one of them (25%) showed GBS 3 pattern.

In patient with GBS who showed no bladder affection, two of them (66.6%) showed GBD 2 pattern while one of them (33.3%) showed GBD 3 pattern.

In our study, the pattern of nerve root enhancement did not correlate with the severity of the symptoms (*P* value = 1 for Hughes scale, *P* value = 0. 486 bladder affection).

Prognosis in GBS Patient with GBS also showed various prognostic sequel 2 weeks after the onset of the disease: completer recovery, walking with aid, and worsening of symptoms.

Patient who showed complete recovery (4 patients), two of them (50%) showed GBS pattern 2 and two patients (50%) showed GBS pattern 3.

Patients who developed walking with aid after 2 weeks (two patients), both showed GBS 2 pattern, while the patient who needed ICU admission for worsening of his symptoms showed GBS 3 pattern.

In our study, the pattern of nerve root enhancement did not correlate with the prognosis (*P* value = 0.429).

ATM

We had five patients with acute transverse myelitis (ATM) (three males and two females), all with LMN

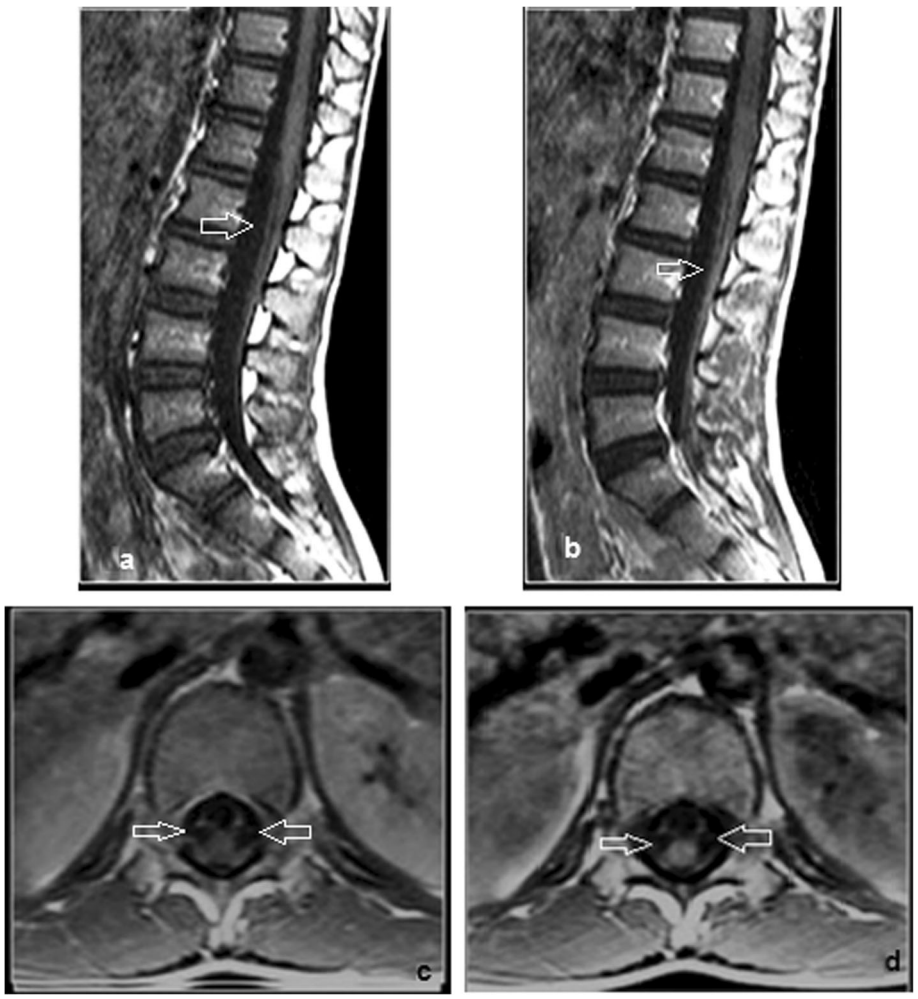

Fig. 6 MRI demonstrates **a**, **c** sagittal and axial T1W show mildly thickened cauda equina nerve roots. **b**, **d** Sagittal and axial post-contrast T1W show anterior and posterior nerve roots of the cauda equina, pattern 3 of contrast enhancement

paralysis. Three patients had a history of upper airway infection prior to the onset of the disease.

Definite diagnosis of those patients was achieved with clinical symptoms of acute lower limb paralysis and MRI findings.

MRI findings Affected areas of the spinal cord were multiple dorsal and cervical spinal lesions in one patient, one patient had affected cervical spinal lesion, and three patients had dorsal spinal lesion.

MRI proved to be a very important diagnostic modality of ATM; abnormal spinal hyperintense T2 signal (Fig. 7) was evident in all patients with ATM, i.e., in 100% of our patients during their initial spinal MRI.

In our study, MRI showed high sensitivity in diagnosis of ATM (100% sensitivity and 100% NPV). However, MRI had about 90% specificity, with 83% PPV. As one patient had cervical cord lesion opposite to C3,4,5 and proven to be MS by clinical assessment as the patient had a history of previous episode of neurological symptoms consistent with MS, patient had no clearly defined sensory level as well as CSF analysis was not suggestive of ATM.

Out of the five patients, one showed multiple segments of signal alteration seen within the anterior aspect of the cervical and dorsal spinal cord, the longest seen opposite C4 down to D1 levels; a patient had a C2, C3, and C4 segment of spinal cord signal alteration at the cervical spinal cord; a patient had D9 down to L1 level segment of dorsal spinal cord signal alteration; a patient had D10 to L1 level segment of dorsal spinal cord signal alteration; and a patient had D7 to D11 level segment of dorsal spinal cord signal alteration,

All the previous patients showed spinal cord signal alteration, eliciting intermediate to low T1W and high T2W signal (Fig. 8).

Clinico-pathological correlation with ATM Three patients out of five (60%) showed grade 2 according to

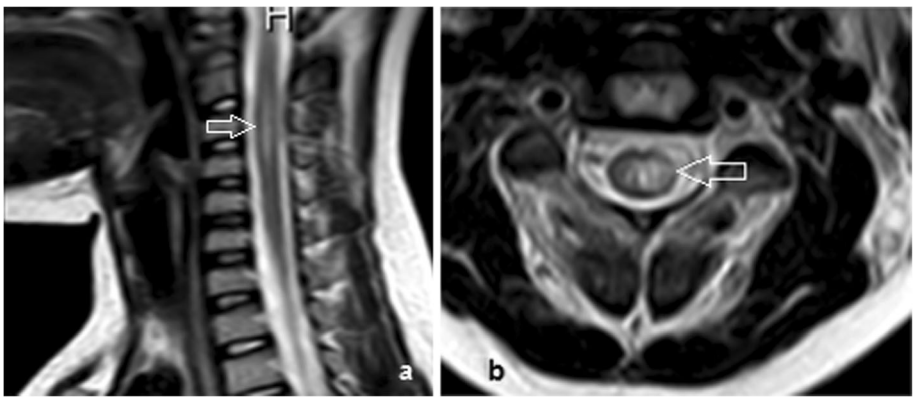

Fig. 7 MRI demonstrates **a** sagittal and **b** axial cervical spine T2W image for a 5-year-old female showing a segment of signal alteration noted at the cervical spinal cord opposite C2, C3, and C4 levels eliciting bright T2 signal

Hughes scale; all three patients showed dorsal cord affection and 4–5 segments by MRI.

Two patients out of five (40%) showed grade 4 according to Hughes scale, one patient showed multiple segment affection in cervical and dorsal cord, longest was 5 segments, and the other patient showed 3 segments of cervical cord affection by MRI.

In the light of our study, patients with higher level of spinal cord affection (cervical cord) demonstrated by abnormal high T2 signal by MRI, showed worse clinical symptoms. As well as the patient with majority of cord segment affection also showed worse clinical symptoms.

All five patients showed bladder affection and sensory level loss.

Prognosis in ATM Three patients with ATM showed complete recovery, all of them showed abnormal high T2 signal and swelling of dorsal cord by MRI.

Two patients with ATM developed walking with aid after 2 weeks, one patient showed multiple segments of abnormal high T2 signal and swelling of dorsal and cervical cord and the other showed abnormal high T2 signal and swelling cervical cord by MRI.

In the light of our study, patients with cervical level of spinal cord affection and with more segment affection demonstrated by abnormal high T2 signal in MRI, showed persistent weakness as bad outcome.

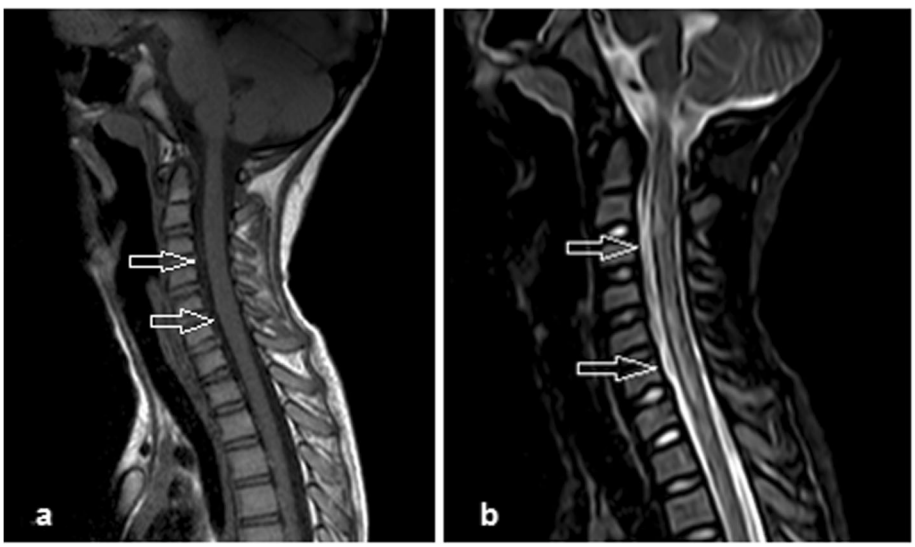

Fig. 8 MRI demonstrates multiple segments of signal alteration are seen within the anterior aspect of the spinal cord, the longest seen opposite C4 down to D1 levels. These elicit low to intermediate sagittal T1W signal (**a**) and sagittal bright T2W signal (**b**) and with associated mild cord expansion

MS

We had three patients with MS, all females, age ranged from 11 to 16. No patients had significant events within 4 weeks prior to the onset of the disease. Definite diagnosis of those patients was achieved with clinical symptoms suggesting MS including episodes of symptoms, MRI findings, and medical treatment response.

MRI findings One patient demonstrated few tiny scattered foci of altered signal intensity involving bilateral fronto-parietal subcortical, high in T2W and FLAIR with no post-contrast enhancement.

One patient showed right occipital subcortical small area of signal alteration and cervical cord short segment of opposite to C3/4 disc, both areas showed altered signal eliciting low T1W signal and high T2W and FLAIR signal (Fig. 9).

Last patient showed cervical spinal cord segment of altered signal showing low T1W signal and high T2W signal opposite to C3,4,5 vertebrae mostly affecting the left half of the cord.

Clinico-pathological correlation with MS One patient who showed cerebral bilateral fronto-parietal tiny plaques exhibited mild symptoms (grade 2 according to Hughes scale).

One patient who showed right occipital and cervical cord short segment also exhibited mild symptoms (grade 2 according to Hughes scale).

One patient who showed long cervical cord segment affection exhibited more severe symptoms (grade 3 according to Hughes scale).

Prognosis in MS Two patients showed complete recovery, one had cerebral bilateral fronto-parietal tiny plaques and the other one had right occipital and cervical cord short segment. One patient developed walking with aid after 2 weeks, she demonstrated long cervical cord segment affection.

In the light of our study, the size and site of the lesion correlated with the symptoms and outcome as the patient with long cervical spinal cord lesion of abnormal high T2 signal by MRI, showed more severe symptoms and worse outcome.

While patients with tiny fronto-parietal plaques and short cervical cord segment lesion demonstrated by MRI showed less severe symptoms and better outcome.

Others

One patient, 11-year-old male, showed acute bilateral lower limb paralysis (LMN) with disability grade 4 according to Hughes scale and Glasgow Coma Scale score of 15 with bladder affection and sensory loss level at the umbilicus. MRI showed a D7 vertebra body and right lamina osseous lesion with soft tissue component compressing the dorsal spinal cord, eliciting high signal in T2W, isointense signal in TIW, and rather homogenous enhancement in post-contrast T1W (Fig. 10), consistent with vertebral neoplastic lesion. The patient proceeded with surgical consultation and oncology for the treatment plan.

Another patient, 15-year-old female, showed acute bilateral lower limb paralysis (LMN) with disability grade 3 according to Hughes scale and Glasgow Coma Scale score of 15 with no bladder affection and no sensory loss. MRI showed a large oval-shaped well-defined intradural extra-medullary soft tissue mass within the spinal

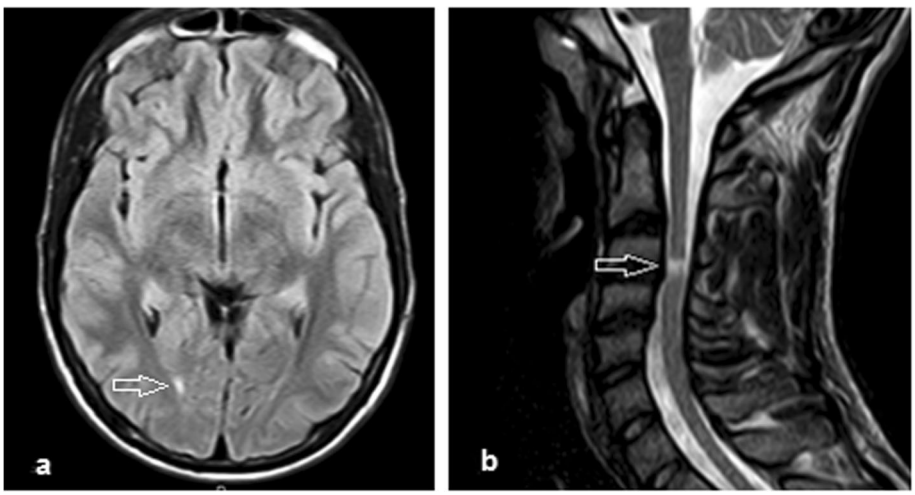

Fig. 9 MRI demonstrates **a** axial FLAIR showing right occipital subcortical small area of signal alteration and **b** sagittal T2W showing cervical cord short segment of high T2W signal opposite to C3/4 disc

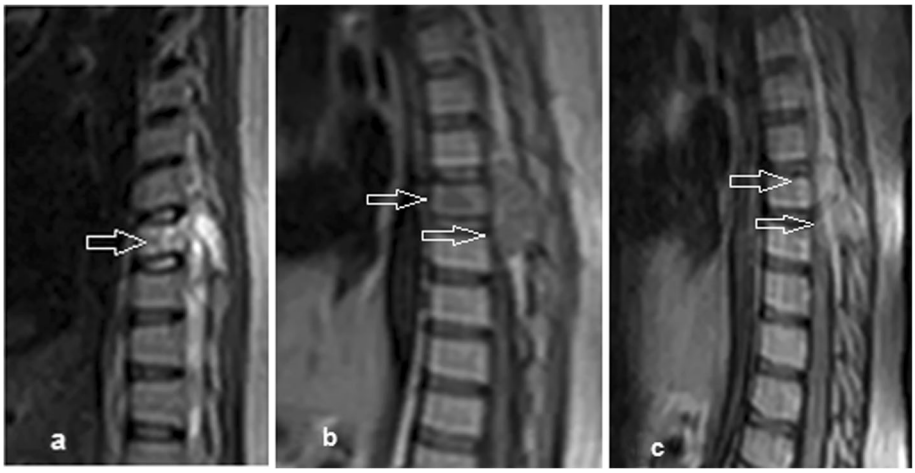

Fig. 10 MRI demonstrates **a** D7 vertebra body and right lamina osseous lesion with soft tissue component compressing the dorsal spinal cord, eliciting high signal in a sagittal T2W, isointense signal in **b** sagittal T1W, and rather homogenous enhancement in **c** post-contrast T1W

canal, opposite to C7 down to D2 vertebral levels. It was seen at left lateral aspect of the thecal sac, compressing the adjacent cord and displacing it to the right side, with left neural foramina extension through C7/D1 and D1/2 with extra-spinal component. It elicits intermediate signal in T1W and T2W with restricted diffusion (Fig. 11), consistent with spinal schwannoma. The patient proceeded with surgical consultation and oncology for the treatment plan.

Another 3-year-old male patient showed acute bilateral lower limb paralysis (UMN) followed by dizziness and rapidly falling consciousness, with disability grade 4 according to Hughes scale and Glasgow Coma Scale score of 10 with bladder affection. He was admitted to the ICU shortly after. MRI showed multiple recent (acute) infarctions seen at the entire left middle cerebral artery (MCA) territory including the left frontal and parietal regions as well as left caudate and lentiform nuclei with mild mass effect over the ipsilateral lateral ventricle and mild midline shift to the opposite site, eliciting intermediate to low T1W signal, high T2W and FLAIR, and diffusion restriction (Fig. 12), consistent with acute infarction. The patient rapidly deteriorated and needed ICU admission.

Discussion

Acute weakness is a broad clinical entity with an array of diagnostic possibilities. A systematic anatomic and clinical approach to diagnosis helps to narrow down the diagnostic possibilities. Accurate and early diagnosis of the cause is important in the management and prognosis.

Since the eradication of poliomyelitis, the other common etiologies relevant for the pediatric age group are acute disseminated encephalomyelitis (ADEM), Guillain–Barré syndrome (GBS), acute transverse myelitis (ATM), and multiple sclerosis (MS) [15].

This study included thirty cases of children less than 16 years old presented by acute bilateral lower limb weakness. ADEM was the most common cause in our study (twelve patients, 40%) followed by GBS (seven patients, 23.3%) and ATM (five patients, 16.7%).

Three patients, 10%, were diagnosed by MS, and three patients showed other diagnoses (spinal tumor, vertebral tumor and cerebrovascular stroke).

In our study, acute weakness was slightly more frequent in males and more common in younger age groups in childhood, the most affected age group was 3 years old.

MRI brain and spine are indicated when there is a suspicion of rapid paralysis, bladder or bowel involvement, sensory loss or sensory level on examination, and appearance of UMN or LMN signs on examination [16].

In our study, MRI proved to be very helpful in the management of children with acute secondary inability to walk if done early in the disease course. In our study, MRI was essential to reach the final diagnosis of such cases combined by clinical assessment. Also in these cases MRI enables rapidly reaching to the final diagnosis and eliminating other possible diseases.

Final diagnosis in our cases was reached by a combination of MRI, clinical assessment, and efficacy of medical treatment.

In our study, MRI was very essential in the differential diagnosis of acute secondary inability to walk in children, especially where the treatment varies greatly, such as in cases of GBS and ATM where rapid diagnosis is very important and the treatment is different.

Determining the type of weakness, whether UMN or LMN, is essential to determine the possible diagnosis

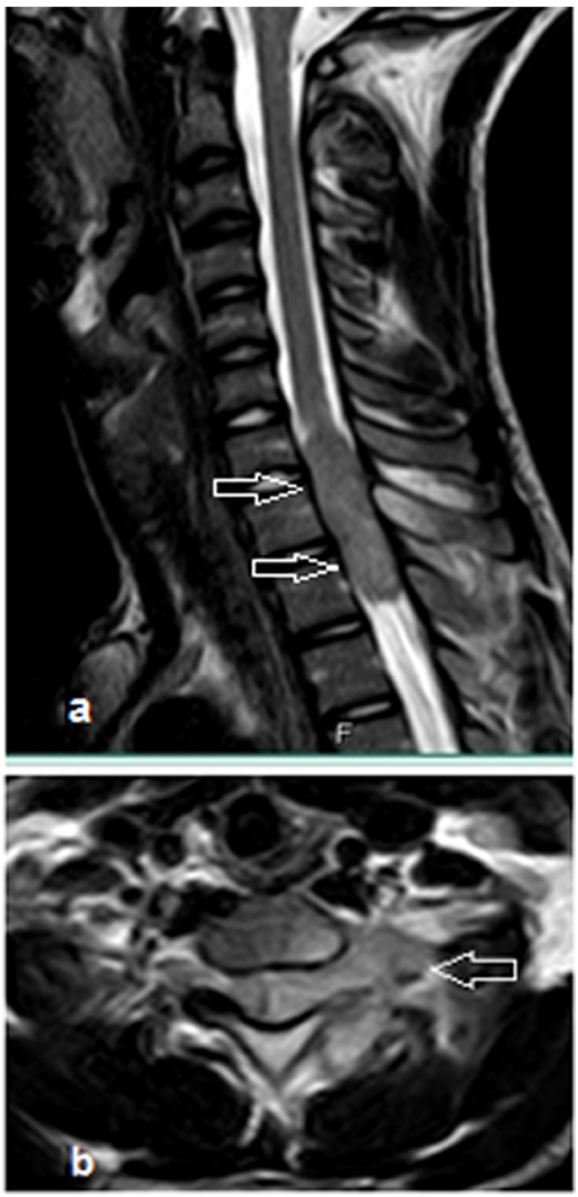

Fig. 11 MRI demonstrates a large oval-shaped well-defined intradural extra-medullary soft tissue mass seen within the spinal canal, opposite to C7 down to D2 vertebral levels. It is seen at left lateral aspect of the thecal sac, compressing the adjacent cord and displacing it to the right side; it shows left neural foramina extension through C7/D1 and D1/2 with extra-spinal component. It elicits intermediate signal T2W (**a**, **b**)

and required MRI study of whether the brain or spinal cord. In our study, 50% of the patients showed UMN while 50% showed LMN paralysis.

ADEM in our study was the most common cause of the acute weakness; most of the patients belonged to the younger age and the most frequently affected age was 2 years old, and it was more common in males.

According to Pohl et al. [17], the radiological diagnostic criteria for ADEM include the presence of demyelinating lesions visualized on T2-weighted and FLAIR sequences. T1-weighted sequences rarely demonstrate hypointense white matter lesions. Lesions are typically located in the centrum semiovale at the junction of cortical gray and white matter. Demyelinating lesions in ADEM may show a varied pattern of enhancement (i.e., patchy or ring-shaped).

MRI is very sensitive in patients with ADEM, as in our study MRI had 100% sensitivity and 100% NPV as all patients with ADEM showed subcortical white mater hyperintense T2/ FLAIR lesions, i.e., in 100% of our patients during their initial brain MRI.

However, in our study, MRI had 66% specificity and 92% PPV. Mainly in our study MRI findings in ADEM needed to be differentiated with patients with MS; however, various MRI diagnostic criteria, mainly the 2010 MacDonald criteria, help in the differentiation [9].

According to Garg [8], our patients showed MRI findings as pattern 1 and pattern 2.

Most affected areas were occipito-parietal, only parietal, and temporo-parietal areas. The patients showed various enhancement patterns (ring and patchy).

In our study, the lesions' size (P value = 1 for Hughes scale and P value = 0.61 for bladder affection), distribution (P value = 0.120 for Hughes scale and P value = 0.377 for bladder affection), and enhancement pattern (P value = 0.639 for Hughes scale and P value = 0. 773 for bladder affection) did not correlate with the severity of the disease symptoms. Our patients in the study (both with severe and less severe symptoms) showed different MRI lesion sizes and enhancement patterns.

Also the lesions' size (P value = 0. 740), distribution (P value = 0.610), and enhancement pattern (P value = 0. 740) did not correlate with the prognosis, as Steiner and Kennedy [18] also depicted.

GBS in our study was the second most common cause of the acute weakness, most of the patients were older age than those with ADEM with 5 years old being the most frequently affected age and it was more common in males.

The diagnosis of GBS is usually reached by clinical examination; however, the consequences of missing other potential diagnoses such as transverse myelitis can be catastrophic. Therefore, spinal MRI is essential not only to confirm the diagnosis but also for exclusion of important differential diagnoses [19].

MRI proved to be very sensitive in diagnosis of GBS, and ruling out its differential diagnosis, i.e., ATM. MRI was very sensitive in our study as it had 100% sensitivity and 100% NPV as well as 100% specificity and 100% PPV, as nerve root enhancement was evident in all

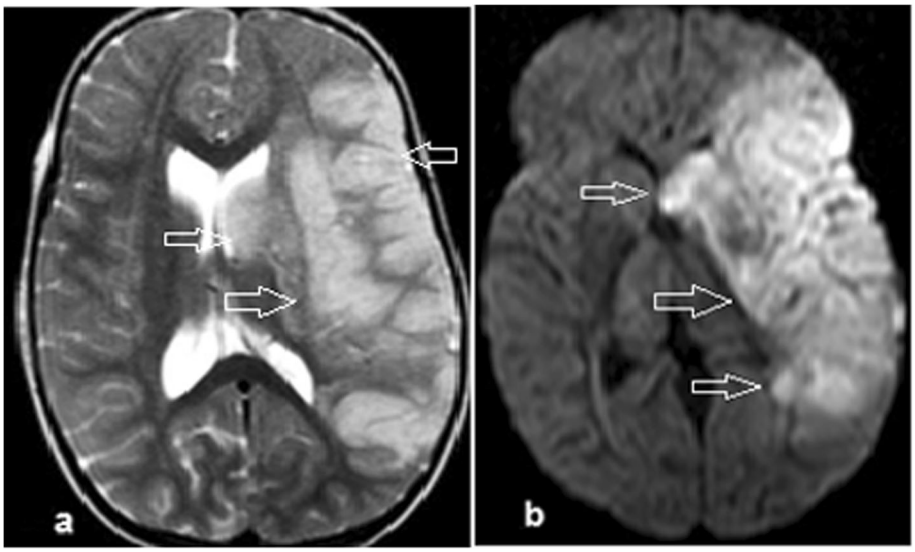

Fig. 12 MRI demonstrates, multiple recent (acute) infarctions seen at the entire left MCA territory including the left frontal and parietal region as well as left caudate and lentiform nuclei with mild mass effect over the ipsilateral lateral ventricle and mild midline shift to the opposite site, eliciting bright T2W (**a**) and diffusion restriction (**b**)

patients with GBS, i.e., in 100% of our patients during their initial spinal MRI.

All patients showed nerve root thickening and enhancement. According to Yikilmaz et al. [11], our patients showed patterns 2 and 3 of nerve root of enhancement.

About 57% of the patients showed pattern 2 nerve root enhancement and 43% showed pattern 3.

As Yikilmaz et al. [11] showed that the pattern of nerve root enhancement did not correlate with the severity of the disease (P value = 1 for Hughes scale, P value = 0.486 bladder affection), our patients in the study both with severe and less severe symptoms showed various nerve root enhancement patterns.

As Yikilmaz et al. [11] also depicted the pattern of nerve root enhancement did not correlate with the prognosis (P value = 0.429), our patients in the study with various outcomes showed both enhancement patterns.

ATM in our study was the third most common cause of the acute weakness with five patients being affected (three males and two females); the patients' age was between 5 and 11.

According to Goh et al. [20], the radiological diagnostic characteristics are a central T2 hyperintense spinal cord lesion extending over more than two segments. More than two thirds of the cross-sectional area of the cord is involved.

MRI was essential in diagnosis of ATM patients; in our study, MRI was very sensitive in patients with ATM, as it had 100% sensitivity and 100% NPV as all patients with ATM showed focal spinal cord swelling with abnormal high T2W signal. However, in our study, MRI had 90% specificity and 83% PPV, as patients with MS also might have spinal cord lesions; obtaining medical history and clinical assessment is essential in those patients.

The patients with dorsal spinal cord affection showed milder symptoms with Hughes scale 2, and the patient with cervical spinal affection and the one with more cord segment affection showed worse symptoms with Hughes scale 3.

Also as Morgan [1] reported, our study showed that the two patients with high cord affections showed bad prognostic outcome in comparison to the three patients with dorsal affection who showed better prognostic outcome.

Three of the patients have MS, all were females with ages ranging between 11 and 15 years.

MRI was essential in diagnosis of MS as patients were diagnosed according to 2010 MacDonald criteria.

MRI features that help identify children of MS include 1 or more non-enhancing T1-hypointense lesions, 2 or more periventricular lesions, and the absence of a diffuse lesion distribution pattern. Two of these 3 criteria were described to be sensitive for distinguishing MS from ADEM [10].

One patient only showed brain lesions, another patient showed brain and cervical cord lesions, and the third patient showed a single cervical cord lesion.

The patient with brain and short cervical cord lesions showed milder symptoms with Hughes scale 2 and good prognostic outcome, while the patient with long cervical spinal affection showed worse symptoms with Hughes scale 3 and needed walking with aid.

In our study, a limited number of patients as regards ATM and MS could be unrepresentative.

In pediatric patients, acute bilateral lower limb weakness can be caused by variety of causes such as compressing spinal cord tumors, as in our study two patients presented acute flaccid weakness of the lower limbs, indicating MRI spine which showed D7 vertebra osseous tumor compressing the dorsal spinal cord, consistent with vertebral osteosarcoma in one patient, as well as an intra-dural extra-medullary soft tissue mass within the spinal canal, compressing the adjacent cord, consistent with spinal schwannoma in the other patient.

Cerebrovascular strokes also can occur in pediatric patients, as in our study one patient showed acute infarction at the entire left MCA territory affecting the left frontal and parietal region as well as left caudate and lentiform nuclei; the patient presented acute lower limb weakness at first and rapidly deteriorated consciousness and needed ICU admission.

A potential criticism in our study was the limited number of cases which could be unrepresentative. Another limitation to be acknowledged also in the study is the lack of documentation.

Conclusion

Acute secondary lower limb weakness is a clinical condition characterized by rapid onset weakness and entails many diagnostic possibilities. MRI is important in rapid reaching of the diagnosis, with T2 sequence is of utmost importance to detect the lesions; also, MRI is helpful in eliminating other differential diagnoses which is essential to orchestrate a proper treatment plan and achieve a rapid full recovery.

MRI brain can differentiate between ADEM and MS as the lesions while both would have subcortical white matter hyperintense T2/ FLAIR lesions,

In ADEM, lesions tend to be ill defined than that of MS. Also both diseases would have multiple lesions as opposed to other conditions which may cause same clinical presentation of acute secondary inability to walk.

Also MRI spine proved helpful to differentiate between GBS where there is thickening and enhancement in cauda equina nerve roots and ATM where there are hyperintense T2 intra-axial spinal cord lesions.

While MRI is shown to be highly sensitive in detecting the lesions, however, the lesions' size, distribution, and enhancement pattern were not an indication to the severity of the disease as well as it did not predict the outcome in ADEM and GBS. In ATM, the lesions' site and number of segment affection at the spinal cord may be helpful in predicting the severity of symptoms and outcome.

Abbreviations

MRI: Magnetic resonance imaging; ADEM: Acute disseminated encephalomyelitis; GBS: Guillain–Barré syndrome; ATM: Acute transverse myelitis; ER: Emergency room; CNS: Central nervous system; MS: Multiple sclerosis; GFR: Glomerular filtration rate; FLAIR: Fluid attenuated inversion recovery; DTPA: Diethylenetriamine pentaacetic acid; UMNL: Upper motor neuron lesion; NPV: Negative predictive value; PPV: Positive predictive value; ICU: Intensive care unit; LMN: Lower motor neuron; MCA: Middle cerebral artery

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Authors' contributions

S. KH was responsible for the data acquisition and analysis, S. MH and O.NM were responsible for data interpretation and images analysis, H. SM was responsible for interpretation of clinical data of the patients and A. KA was responsible for final data revision. All of the authors are responsible to the design and implementation of the research, to the analysis of the results, and to the writing of the manuscript. The authors read and approved the submitted manuscript version. The authors agreed both to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved and the resolution documented in the literature.

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Availability of data and materials

The datasets used and/ or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study was approved by the research ethics committee of the Faculty of Medicine at Ain Shams University, in Egypt, on 3 July 2017, reference number of approval: FMASU MD 188/2017.
Consent for participation was signed by the parents for each patient, as the patients were less than 16 years old.

Consent for publication

Consent for publication was signed by the parents for each patient, as the patients were less than 16 years old.

Competing interests

The authors declare that they have no competing interests.

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