Original ResearchArticle

IMPORTANCE OF MRI IN THE EVALUATION OF BRACHIAL PLEXUS INJURIES

Abstract

There isa global increase in the incidence ofbrachial plexus injuries (BPI) due to the increasing participation in extreme sports and theincreasednumber of motorvehicle accidents survivors. Detailedclinicalexaminationisfollowed by MR imaging.The studywasconducted on 30 patients of BPI. The patients withflailupperlimbs andsuspected root avulsions weresubjected to MRI immediatelywhileothersunderwent MRIafter 4-6 weeks.MRI helps to classify an injury as pre- and post-ganglionic or mixed1, specially in patientswherethere are bothpre- and postganglionic injuries which are difficult to assess. This isimportant as timing and type of surgerydepends on whether the injuryispre- or postganglionic.Werecommendthat full upperlimbshouldbeimaged (only T2W/STIRsequence can bedone) to look for muscle edema pattern and movements of diaphragm must beassessed. Contraststudies can alsobeadded if not contraindicated.

Keywords : brachial plexus injuries, MRI imaging, Motorvehicle accidents, atrophy

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Introduction:

The upperextremitiesderivetheirmotor as well as sensory innervation through brachial plexus, a major neural structure. Motorvehicle accidents are major source of injurythough sports, radiation injuryetcalsocontribute. There is global increase in the incidence of brachial plexus injuries (BPI) due to the increasing participation in extreme sports and the increasednumber of motorvehicle accidents survivors. Detailedclinicalexaminationis followed by MR imaging. The major role of MRI is to distinguishpre- frompostganglionic injuries, to grade the injuries (Sunderland classification – table 1) and pick up obscure injury with the help of indirect signs like extent and pattern of muscle edema and/or atrophy.

Methods:

The studywasconducted on 30 patients of BPI. The patients withflailupperlimbs and suspected root avulsions weresubjected to MRI immediatelywhileothersunderwent MRI after 4-6 weeks. MRI wasdone on 3 Tesla system (GE Healthcare Discovery 750W with GEM Suite, Milwaukee, WI, USA) usinghead-neck fortycoil. Axial T2W (TE=114ms, TR=4800ms, FOV=22cm, slice thickness=5mm, spacing-1mm, frequency=512, band width=50), coronal 3D/STIR (TE=102ms, TR=7000ms, FOV=40cm, slice thickness=2mm, spacing=0, frequency=256, band width=35.71), coronal T1W (TE=7ms, TR=456ms, FOV=22cm, slice thickness=4mm, spacing=0, frequency=352, band width=62.5), STIR neurography (TE=90.9ms, TR=16081.3ms, FOV=40cm, slice thickness=3mm, spacing=0, frequency=100, band width=250), and DW neurography (TE=73.8ms, TR=7000ms, FOV=30cm, slice thickness=4mm, spacing=0.5mm, frequency=100, band width=190) sequencesweredone. In addition, oblique sagittal T2 fat sat (TE=110ms, TR=5885ms, FOV=25cm, slice thickness=4mm, spacing=1mm, frequency=288, band width=31.25)

sequencewasdone on shoulderipsilateral to injured brachial plexus, axial STIR (TE=42ms, TR=5465ms, FOV=35cm, slice thickness=4mm, spacing=0.5mm, frequency=352, band width=41.67) of ipsilateral arm, sagittal T2W (TE=76ms, TR=3105ms, FOV=16cm, slice thickness=2.5mm, spacing=0.2mm, frequency=288, band width=35.7) of cervical spine and axial cube T2 (TE=90mm, TR=1360mm, FOV=24cm, slice thickness=1.6mm, spacing=0, frequency=288, band width=83.33) of cervical spineweredone.

Location of injurywasidentified, whether the injurywas at root, trunk, division, cord or terminalbranchlevel and whetheritwaspre- and/or postganglionic. Further, injurywasgraded according to Sunderland classification (Table 1). MRI findingswerecorrelatedwithclinical examination at the time of injury/MRI and on follow-up at threemonths.

Results and Discussion:

The patients rangedfrom 11 days to 58 yearswithmeanage of 29.4±12.09 yearswith 26 males and 4 females. 14 patients hadleftsided, 12 right sided and 4 bilateralinjury. Nerve rootswereinvolvedin 18, trunksin 17, divisions in 5 and no direct injury of brachial plexus wasseen in one patient. Ten patients hadpreganglionicinjury, 17 hadpostganglionicinjury whilethreehadbothpre- and postganglionic injuries.C5 nerve root wasinvolvedin 21 patients, C6 in 27, C7 in 18, C8 in 19 and T1 in 14 patients. Grade I injurywasseen in three patients, grade III in nine, grade V in eight and multiple grades of injuries wereseenin 10

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patients. No isolated grade II and IV injuries wereseen. Figure 1 to 8 show someselected cases. There was excellent correlationbetween MRI and clinicalfindings. 23 cases showed totalcorrelation, sevenshowed partial correlation. Six patients showedcompleterecovery, sixshowed partial recoverywhilethreeshowed minimal recovery and 15 no recovery. Patients havinglower grades of injury (grade I/II) showedcompleterecovery and thosewith higher grades and extensive injuryshowed minimal or no recovery.

MRI helps to classify an injury as pre- and post-ganglionic or mixed1, specially in patients wherethere are bothpre- and postganglionic injuries which are difficult to assess. This is important as timing and type of surgerydepends on whether the injuryispre- or postganglionic. In ourstudypreganglionicinvolvementwasseenin 10 patients and post ganglionicin 17 whilebothpre- and post-ganglionic injuries wereseenin 3 patients.
Each BPI isdifferent. Brachial plexus injuries must beassessed in terms of extent of injury, site of injury (nerve roots, root/trunk/division/cord/terminal branches involved, pre- or postganglionic), grade of injury, associated injuries and status of othersurrounding structures
like muscles and nerves to decidetreatment (conservative or surgical, type of surgical treatment, timing of surgery) and prognosis. Status of surrounding muscles and nerves helps in decidingtheir utility for nuerotization. Nerve rootswithpre-ganglionicinjurycannotbeused as a nerve source for reconstruction, whereas in postganglionic injuries, connection to CNS is intact and the nerve can beused as a source of axons2.
Detailedexaminationis a must to assessmotor and sensoryfunctions, presence or absence of Horner's syndrome, to know the dermatomes and myotomes involved and whether the injury
ispre- or postganglionic. Somesigns of preganglionicinjury are Horner's syndrome, injury to very proximal nerves like the long thoracic nerve (winging of scapula), dorsal scapular nerve (rhomboidparalysis) and phrenic nerve (paralysis of ipsilateralhemidiaphragm), severe pain in an anaestheticextremity, constant burning background pain and periodicsharpparoxysms of shooting pain and absence of Tinel'ssign in supraclavicular fossa3. This givesidea about theextent of injury and whetherearlyimaging and treatment are required.
EMG at rest and withactivityhelps diagnose and localize the level of the lesion. Denervation

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changes can beseen in proximal muscles as early as 10 to 14 daysafterinjury and 3 to 6 weeks post injury in distal muscles4. It can estimate the severity of axonloss, and completeness of the lesionwhichisdifficult on MRI. EMG can alsodistinguishpreganglionicfrompostganglioniclesions. EMG can evaluate muscles that are difficult to test clinically and can quantify the extent of denervation. Because of Walleriandegeneration, the EMG signs of denervation are not reliablydemonstrateduntil 3 to 4 weeksafter injury5, and hencethisexaminationshould not bedoneearlier. EMG isalsoused in serial evaluations of the injury, to search for signs of reinnervation, which are seenseveralweeksbefore the onset of detectablevoluntary muscle contraction3. EMG recoverydoes not alwaysequatewithclinically relevant recovery, either in terms of quality of regenerate or extent of recovery. Conversely, EMG evidence of reinnervationmay not bedetected in completelesionsdespiteongoingregeneration, whentarget end organs are further distal4. Complex muscle action potentials (CMAPs) are not useful in complete distal lesionsbecause of the necessary time for regeneration to occurinto distal muscles, but are useful in partial lesionswheretheir size isproportional to the number of functioning axons4. Nerve conduction velocitystudies can alsodifferentiatepre- frompostganglionicinjury. Spinal or cortical potential (SEPs) cannotbeelicited in preganglioniclesions, despitetheir normalperipheralsensory NCV. Both NCV and SEPs are absent in postganglioniclesions as well as in combinedpre and postganglionic lesions3. Negative SEP examinationisclinically moreusefulthan a positive one3. Pre or post ganglioniclocalization of lesion can bedonewith the help of sensory nerve action potentials (SNAPS). In a preganglioniclesion, inspite of the extremityhaving no sensation in the distribution of the affected nerve root, therewillbe SNAPs. The SNAPs are not present in postganglionic or combinedpre- and postganglionic lesions6. Electrodiagnostic studiesrevealsubclinical injuries and recognize recovery6.

The presence of NAP indicates the viability of thousands of axons ratherthanhundreds as seenwithother techniques like SEP whereintegrity of few hundredfibersissufficient for positive response. Hence NAP more stronglycorrelateswithrecoverythan SEP. More than 90% of patients with a preserved NAP gain clinicallyuseful recovery4. The presence of NAP bodeswell for recoveryafterneurolysisalone, without the need for additionaltreatmentlike neuromaresection and grafting. However, thereis no adequateperipheral stimulation site for C5 root3 and hence NCV studiescannot help in C5 root injuries.

MRI is the imaging investigation of choice. It can directly show preganglionicinjury.

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Expansion of extravascularbed and extracellularspace can lead to enhancement of paraspinal muscles as early as 24 hoursafterinjury. This can help in identifyingfunctionallyimpaired nerverootsevenwhentheiranatomyispreserved and guide surgeon in avoiding abortive reconstructiveprocedures. Contrastenhancementis an accurate indirect sign of root avulsion injury [6]. However, timing of MRI isvery important. MRI shouldbedeferred for 3 to 4 weeks as clearpicture of injuryappears once nerve injuryisdemarcated and edema, hematomas and inflammation of acute phase subside, but there are some situations where urgent surgicaltreatmentisrecommended like major vascular injuries, root avulsions, flailupperlimb, sharp open injuries, high velocitygunshot wounds6. In such situations, MRI shouldbedone as early as the patient stabilizes. It isvery good at directlyshowing brachial plexus as well as showing indirect signs of nerve injury like muscle denervationedema. In our case number 7, no direct injury to brachial plexus couldbeseen, but edema of serratus anterior muscle suggestedinjury to long thoracic nerve. Many of our patients showededema of trapezius, a muscle supplied by spinal accessory nerve. Thoughthisis not related to brachial plexus, but likelyinjury to spinal accessoryrules out possibility to use this nerve for nerve grafting or neurotization and hencehelps surgeon in decidingwhich nerve to harvest for thispurpose. MRI, in conjunctionwith EPS, can grade injuries whichhelps in deciding the type of treatment. Grade I and II injuries mostlyrequire conservative treatment, while grade III injuries maybetreatedconservatively or surgically. These patients shouldbetreatedconservatively to allow time for naturalreinnervation and if thereis no improvementafter 3 months, surgicaltreatmentshouldbeplanned. Grade V injuries, wherethereis gap in the nerve, can betreatedwith nerve grafting (sural nerve is one of the best donor nerves which can providegraftupto a length of 30cm).

Our case number 2, 6, 8, 12, 19, 20, 25 and 28 had grade V injury and case number 6, 13, 14, 16 and 28 showedmeasurable nerve gap on MRI, makingthemideal candidates for nerve grafting. By giving the size of gap, MRI helps in planning the source and length of graftneeded.

Grade IV injuries (neuroma in continuity) shouldbeassessedintraoperativelywith EPS. If thereis nerve action potential (NAP) across the neuroma, itmeansthatreinnervationistaking place and onlyneurolysismaybesufficient, but if thereis no NAP acrossneuroma, the neuroma has to beexcised and nerve grafting done3. Preganglionic injuries are alwayssurgical candidates and requireearlysurgery. Nerve graftingis not possible in

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preganglionic injuries due to absence of proximal stump. Neurotization or nerve transferis the treatment of choice in such cases. The status of surrounding nerves, muscles, etc. shown by MRI helps in decidingwhich nerve to harvest for neurotization. Even fracture ribs are important because in cases of fracture ribs, adjacent intercostal nerves are mostlyinjuredmakingthemunlikely candidates for use in nerve transfers. Nerve root repair and re-implantation of ventral rootsinto spinal cord are emerging techniques7. The end-to-sideneurorrhaphywithremoval of the epineuralsheathis an up-to-date surgical technique8. Assessment of muscle atrophy and fattydegenerationusing quantitative three-point Dixon MRI sequence can reflect active flexion and muscle force after BPI9.

MRI examination can addconsiderable value to the evaluation of these patients, since the clinicalexaminationisoftenfraughtwith false negatives and positives. There werethree patientsduringourstudywho came for MRI brachial plexus withclinicaldiagnosis of brachial plexus injury, but whoshowed normal brachial plexus on MRI, but hadtears of surrounding muscles. Theycould not move theirupperarmsproperly due to muscle tear and alsohad pain giving false impression of brachial plexus injury. These cases wereexcludedfrom the study. Here, MRI didgreat value addition by ruling out brachial plexus injury and changingtreatmentdecision. One patient had a fall and then has symptoms of brachial plexopathy, but imagingshowed brachial plexus involved by carcinoma (Fig.9) and therewas no sign of injury to brachial plexus. Another patient had brachial plexopathy due to cervical rib (Fig.10). In the latter two patients, minor trauma justdrew attention towards the pathologywhichwas

diagnosedonly on MRI examination. Cervical spondylosisisanothermimicker of brachial plexopathy. MRI examinationmostlyestablishes the cause of symptoms in such cases. Cervical spineshouldalwaysbeimagedalongwith brachial plexus. MRI not onlychangeddiagnosis in these patients, italsoadded value to the cases whereclinicaldiagnosiswascorrect. In case 1, MRI pinpointed the injury to C5-C6 level, whileclinicalexaminationsuggested pan-brachial plexus injury. In case 6, MRI showedmedialcordinjurywhichwasmissedclinically, reexaminationshowedweakness of thumb and index finger consistent withmedialcordinjury. In case 12, MRI correctlylocalisedinjury to postganglionic segment whileclinicalexaminationsuggestedpreganglionicinjury. In case 15, MRI picked up right lateralcordneuroma and left brachial plexus injuries whichweremissed on

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clinicalexamination. Subtle opposite plexus injurywerepicked in addition to the othersideinjury in case 25 and 30. In cases of pan-brachial plexus injury (case 17), MRI could grade different injuries, thushelping in treatment planning.

Moreover, in cases whereitwasdifficult to make out exact nerve structures injured due to edema, hematoma and inflammation, muscle edema pattern identified on MRI helpedreach a

decision as in case 20.

The judicious and complementary use of all these techniques ultimatelyhelps in deciding type

oftreatment, timing of treatment and guiding and monitoring response. If electromyography suggeststhat the damage is non-degenerative, conservative management is indicated6 which includes slings, splints, physicaltherapy, passive range of movements, electrical stimulation andtherapeutic massage for edema and scar management and adequate pain relief. An advancingTinel'ssignsuggests a recovering lesion4. Persistent pain (lasting for more than six months) is a badprognosticsign for neurologicalrecovery, no matterwhere the lesionis located3. If thereis no recovery in few months, reconstruction shouldbe planned6. Surgeryis alsorecommended in patients withclinical and EMG signs of recovery of distal branches instead of proximal axons8. Spontaneousreinnervationsrequiressome time, but more than 6 to 18 months' denervation can lead to motor end plate failure10. In general, the optimal time of surgical intervention isregarded as 3 to 6 monthsafter injury11. Nerve reconstruction should not beattempted more than 9 monthsafter the accident. There iscompletedisorganization and muscle isreplaced by fatty tissue twoyearsafter injury8. Recovery of elbow flexion ismost important followed by shoulder abduction. Restoration of not onlymotorfunction, but also sensation shouldbeaimed for prevention of injuries, and modulation of the pathogenesis of the deafferentationpathway of pain6. Arthrodesis, tendon transfer, and functional free muscle transplantation are othertreatment options8 where nerve grafting/neurotizationis not possible.

Outcomedepends on patient'sage, intervalbetweeninjury and surgery (denervationperiod), thetwo coaptation sites, long nerve grafts, scar tissue, ischemia and the degree of root lesion3.

The ultimateaimshouldbe to make patient at least self-reliant in dailyactivities.

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Diagnostic accuracy of MRI has been widelyreported in literature. MRI washelpful in making the diagnosis in presence of nondiagnostic EMG & NCV1. There are limitedstudies on the impact of MRI on treatment and outcome. Chhabra et al foundmoderate to major impact of MRI in the evaluation of the majority of upperextremity neuropathies (84%)12. In addition, negativeexaminationresultsallowed the patients to forgofurtherexpensivework-ups, and surgerywasavoided in such cases.

Our studyhadsome limitations too. The overallsample size wascomparativelysmallowing to time constraint. Forearm and hand muscles were not imaged for edema. Diaphragm movementswere not assessed and contrastenhanced MRI was not donewhichcould assist in refiningdiagnosis of preganglionicinjury. Contraststudies can speciallybehelpfulwherethereis no pseudomeningocele formation and suspicion of preganglionicinjuryis high. Based on our observations, werecommendthat full upperlimbshouldbeimaged (only T2W/STIR sequence can bedone) to look for muscle edema pattern and movements of diaphragm must beassessed. Contraststudies can alsobeadded if not contraindicated.

Conclusion:

MRI isveryuseful in properdiagnosis and assessment of extent of brachial plexus injury helping in decidingtreatment (conservative or surgical) and timing of surgery. MRI also assessessurrounding normal muscles and nerves in terms of theirsuitability for nerve transfer.

Compliance withethicalrequirements:

All proceduresfollowedwere in accordance with the ethical standards of the responsible committee on humanexperimentation (institutional and national) and with the Helsinki Declaration of 1975, as revisedin 2008 (5). Informed consent wasobtainedfrom all patients forbeingincluded in the study. This article does not containanystudieswith animal subjects.

Consent :

Writteninformed consent wasobtainedfrom the patients for publication and anyaccompanying images. A copy of the written consent isavailable for review by the Editor-in-Chief of this journal on request.

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Degreeofnerve injury	MRN(signalintensity)	Recovery potential	Surgery
INeurapraxia	Nerve-increased T2 Signal intensityMuscle-Normal	Full	None
IIAxonotemesis	Nerve-increasedT2signalintensityanddiffusely enlarged	Full	None
III	Fascicles-enlarged or effaced due toedemaMuscles-denervation	Usuallyslow,incomplete	None orNeurolysis
IVNIC-neuromain continuity	Nerve-focally enlarged withheterogeneous signal intensity.Underlying diffuse abnormality±fasciclesdisruptedwithheterogeneousSI-NIC Muscles-denervation	Poor tonone	Nerverepair, graft ortransfer

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VNeurotmesis	Complete nerve discontinuity ±hemorrhage and fibrosis in the nervegapandend-bulbneuromaproximally.Epineurial thickening Muscles-denervation	None	Nerverepair, graft ortransfer
Degreeofnerve injury	MRN(signalintensity)	Recovery potential	Surgery
VI Mixed injury(ItoV)	Variable findings along thecircumferentialsegment ofthenerve(I-V) with heterogeneous signal intensitydueto fibrosis	Variable,canbepoortonone	Neurolysis,nerverepair,graft ortransfer

Table 1: Table showingdegrees of postganglionic nerve injuries (Sunderland classification)

Figure Legends:

Fig 1

(a) 3D T2W/STIR coronal images showingslightthickening and hyperintensity of left C5 & C6 postganglionicroots and uppertrunk

(b) T2W/STIR coronal image showingedema in leftsupraspinatus and infraspinatus muscles

Fig 2

(a) 3D T2W/STIR coronal image showingpseudomeningocele at right C6 root (white arrow)

(b& c) Coronal diffusion weighted image &negative image showingkinking of Posteriorcordlaterally (therewashealed fracture rib at this site) (bluearrow) anddiscontinuity and end neuroma at proximal fragment (redarrow) at medial

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cord

(d) T1W axial image showingatrophy of infraspinatus, subscapularis, pectoralis major and minor

Fig 3

(a) Coronal diffusion neurographyshowing normal brachial plexuses

(b) T2W/SPIR axial image showingedema and atrophy of right serratus anterior muscle (arrow)

Fig 4

(a, b & c) 3D T2W/STIR coronal, T2W sagittal cervical spine, coronal diffusion neurography show pseudomeningocele s/o preganglionicinjury to left C6, C7, C8 & T1 nerve roots, thickening and irregularity of leftpostganglionic C6, C7, C8 and T1 nerve roots and left middle and lowertrunks

(d) T2W/STIR coronal image showingedema of supraspinatus, infraspinatus, fracture leftupperribs and left pleural effusion

Fig 5

(a) T2W/STIR coronal image showingpseudomeningocele at right C7 nerve root level (C6-C7 neural foramen)

(b) T2W/STIR coronal image showingdiscontinuity of postganglionic C5 (redarrow) and C6 (yellowarrow) nerve roots

(c) T2W/STIR sagittal image showingthickening, hyperintensity and blurredfascicles of lateral, posterior and medialcords

(d) T2W/STIR oblique sagittal image showingedema of supraspinatus, infraspinatus, subscapularis and teres minor muscles

(e) T2W axial image showingatrophy of pectoralis major, minor and alsoinfraspinatus andsubcapularis muscles

Fig 6

(a& b) 3D T2W/STIR coronal image and itsnegativeshowinghyperintensity and thickening of B/L C5, C6, C7 & C8 postganglionicroots and neuroma in continuity in right lateralcorddistally (arrow)

(c) T2W/STIR oblique sagittal image showingslightdenervationedema in right supraspinatus, infraspinatus, teres minor and deltoid muscles

(d) T2W/STIR axial image showingedema of biceps brachii muscle (arrow)

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Fig 7

(a) T2W axial image showingpseudomeningocele at left D1-D2 neural foramen (arrow) (preganglionicinjury D1)

(b& c) 3D T2W/STIR and diffusion neurography coronal images showingthickening, irregularity and hyperintensity of left C5 nerve root and neuroma in continuity (arrow) in left C7 postganglionic root

(d) Negative image of diffusion neurography coronal image showing normal cords on rightside (redarrow) and discontinuouscords on leftside (black arrow)

(e) T2W/STIR coronal image showingedema in leftsupraspinatus and subscapularis muscles

Fig 8

(a& b) 3D T2W/STIR coronal image and itsnegativeshowingentanglement and probable discontinuity of leftupper and lowertrunkwith a small (5mm) gap in lowertrunk (arrow)

(c) T2W?STIR oblique sagittal image showingedema in supraspinatus, infraspinatus withtear in superior aspect of subscapularis muscle

Fig 9

T1W coronal image showinginvolvement of left brachial plexus by carcinoma larynx

Fig 10

(a& b) Coronal diffusion neurography and itsnegative image showing indentation of right brachial plexus by cervical rib

(c) T1W oblique coronal image showinggrossatrophy of supraspinatus, infraspinatus andsubscapularis

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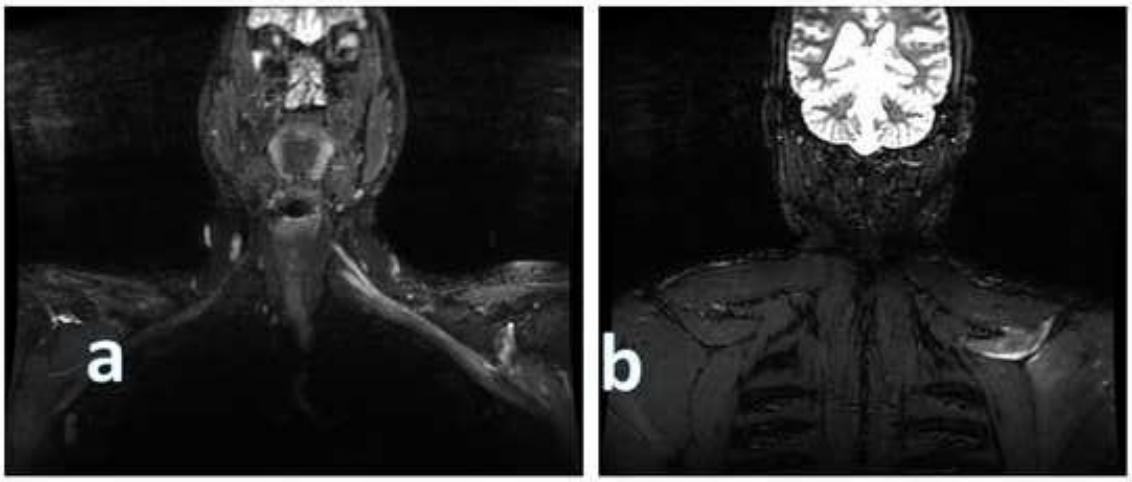
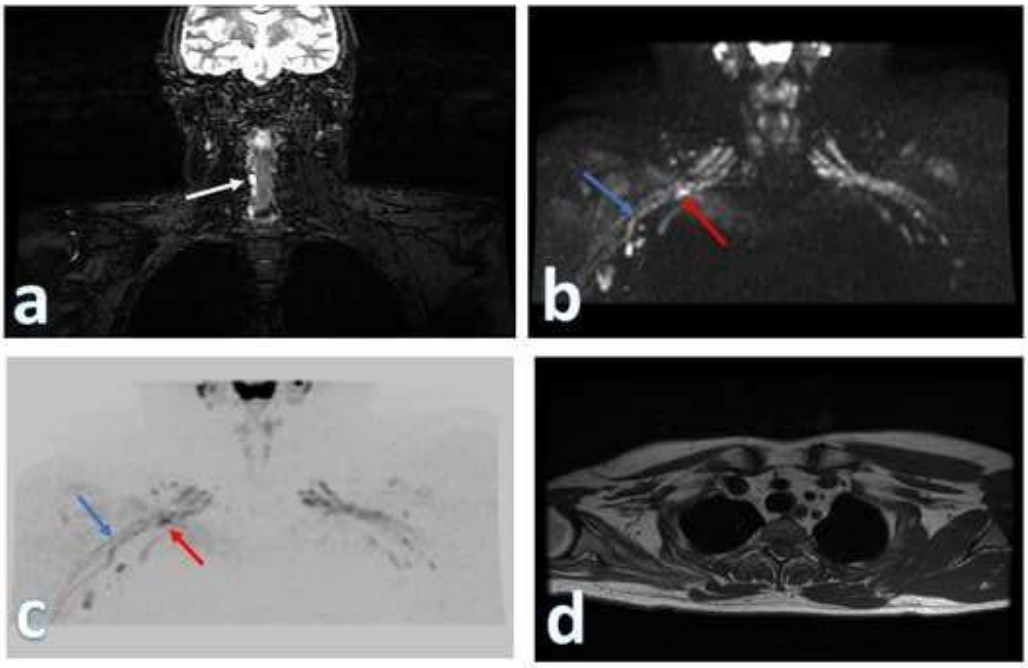


Fig.1



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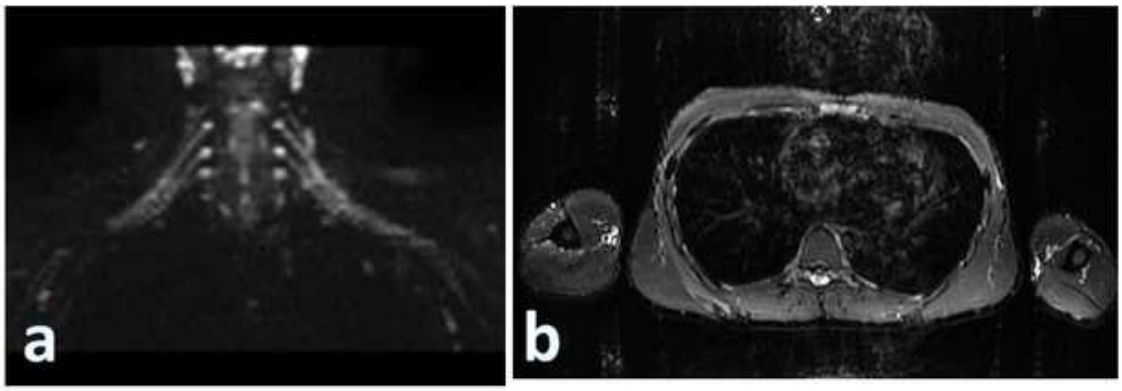

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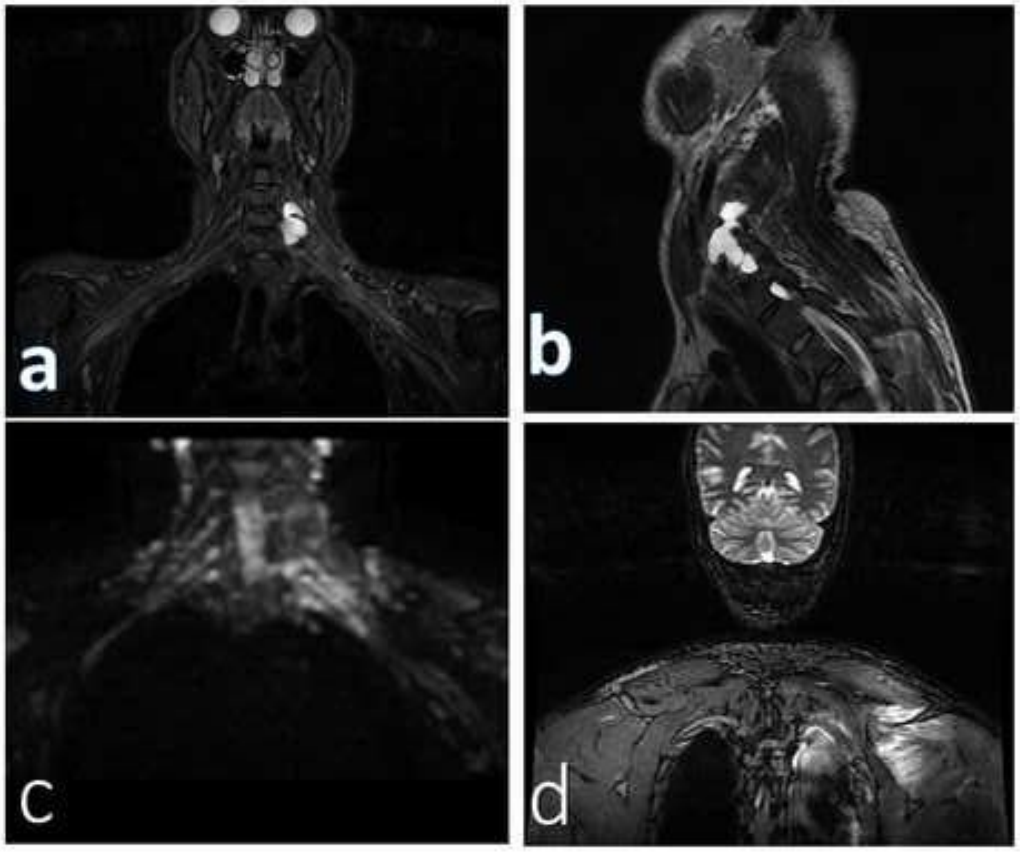

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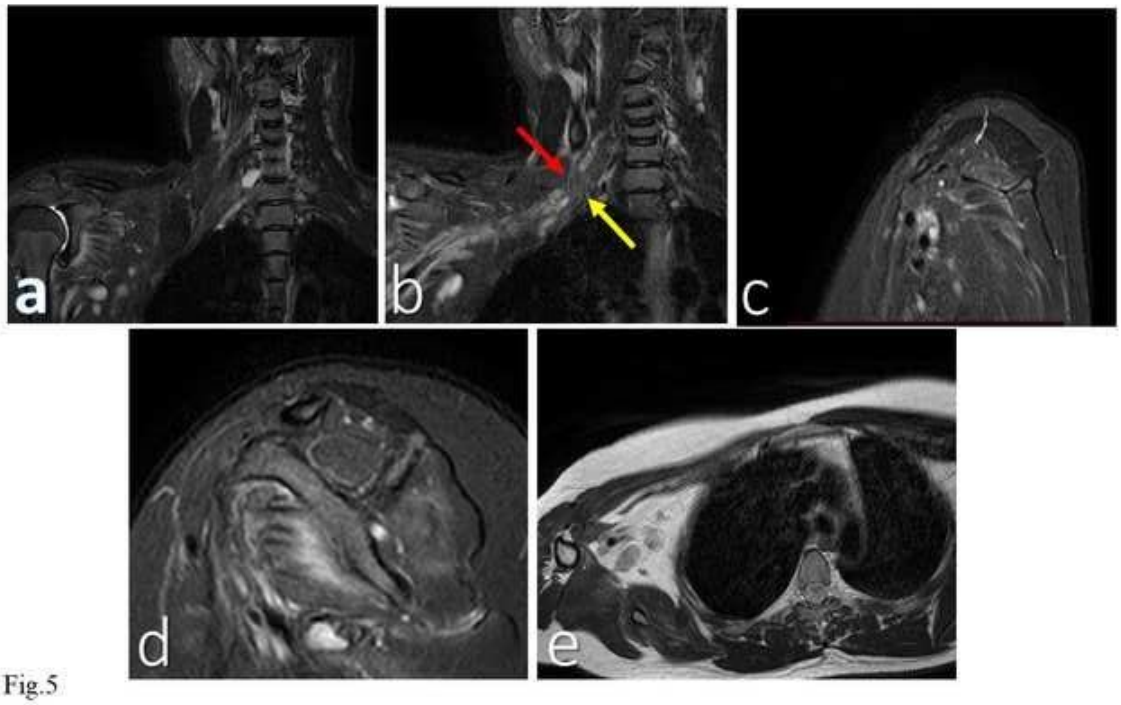
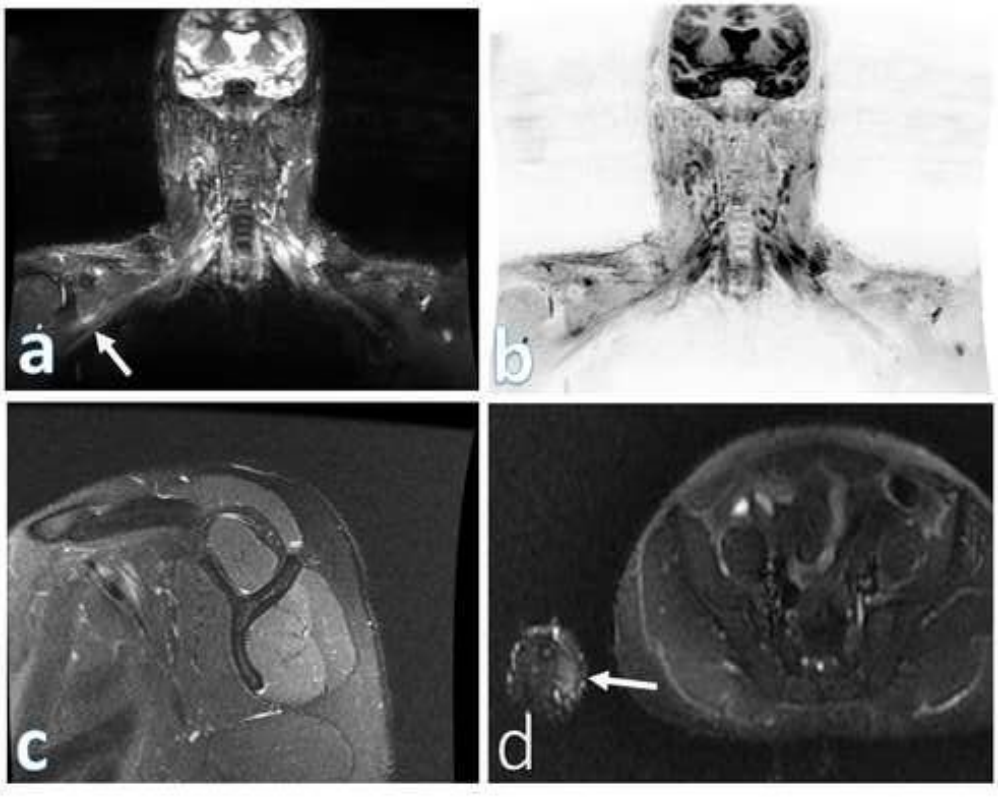


Fig.5



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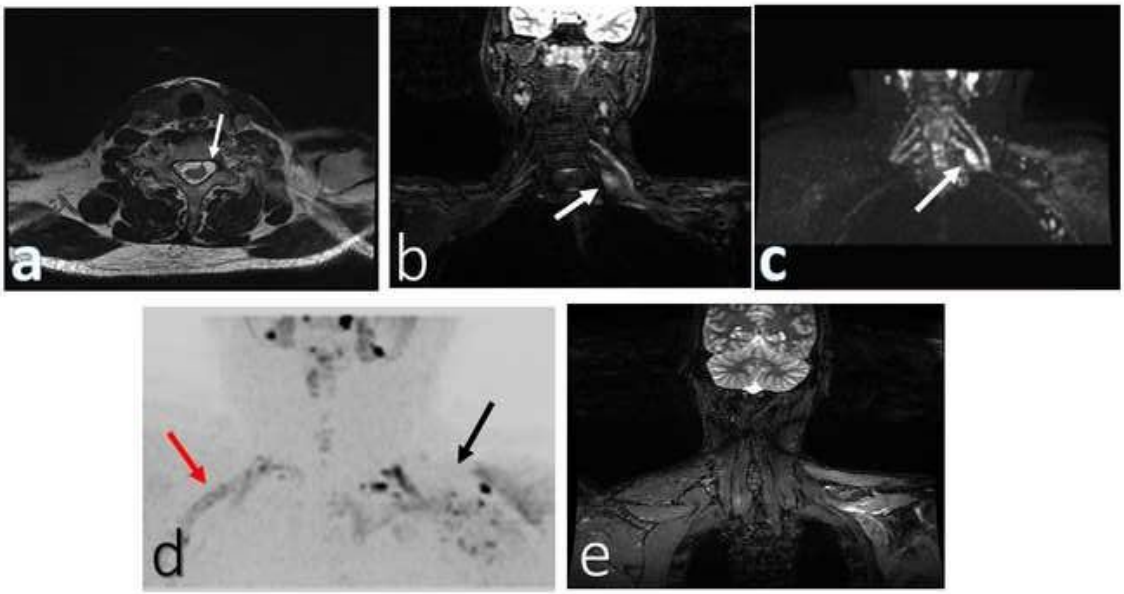

Fig.7

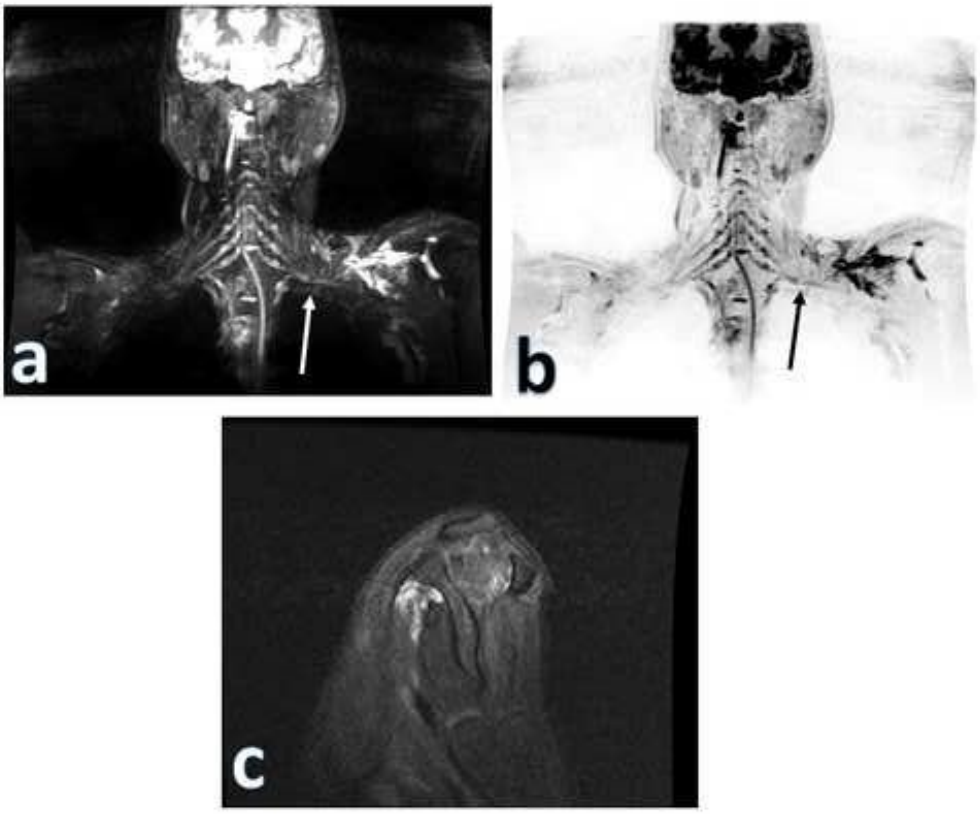

Fig.8

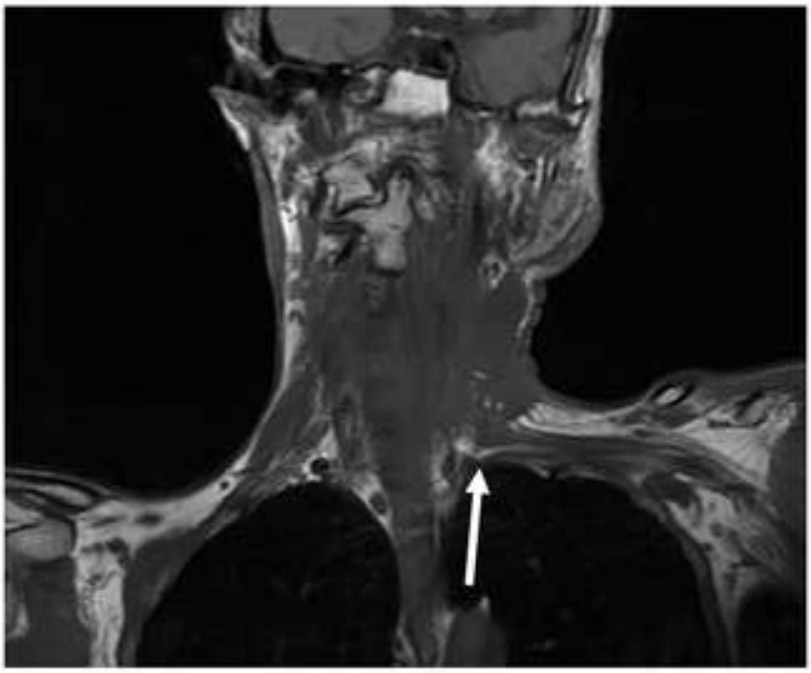

Fig.9

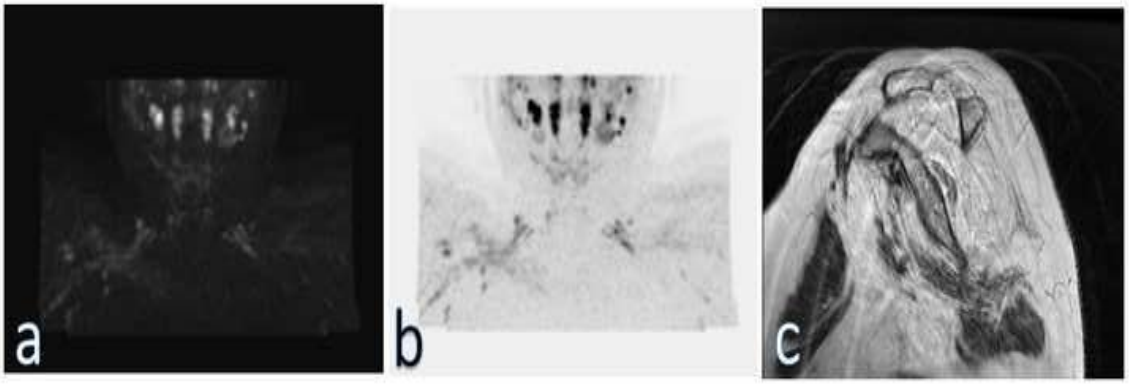

Fig.10