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Compared study of routine magnetic resonance imaging and diffusion tensor tractography on the predictive value of diagnosis and prognosis in acute cervical spinal cord injury

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ABSTRACT

Objective: To compare and analyze the predictive value of two kinds of classification methods, routine magnetic resonance imaging (MRI) and diffusion tensor tractography (DTT), on the diagnosis and prognosis in different degrees of acute cervical spinal cord injury (ACSCI).

Methods: A total of 35 patients with ACSCI treated with surgery in our department from January 2013 to December 2014 were included and all patients had received MRI examination and diffusion tensor imaging examination before surgery. The motor score, sensory score and abbreviated injury scale (AIS) of American Spinal Injury Association were used to evaluate the neurological function of patients before and one year after surgery, respectively. Routine MRI was divided into 3 grades according to the compression and signals of spinal cords and DTT was also divided into 3 grades according to continuous levels of fibre bundle. The correlations between routine MRI grades and DTT grades and the neurological function of ACSCI before surgery and after surgery were analyzed, respectively.

Results: There were no correlations between MRI grading and the motor score, sensory score and AIS of patients with ACSCI before surgery and after surgery. DTT grading showed no relations with the motor score, sensory score before surgery but were related to AIS before surgery. DTT grading was all related to the motor score, sensory score and AIS after surgery.

Conclusions: The noninvasion of DTT showed spinal nerve fibers has a higher predictive value on the diagnosis and prognosis of ACSCI than routine MRI.

1. Introduction

The pathogeny of acute cervical spinal cord injury (ACSCI) includes acute compression injuries, such as cervical fracture and dislocation, acute cervical internal disc herniation and hyperextension injury or whiplash injury of cervical vertebra; penetrating wound and incised wound of sharp instruments, and acute ischemic injury of spinal cord mostly caused by the injury of the anterior or posterior spinal artery or the radicular artery. All kinds of traumas are the commonly causes leading to acute compression injuries of cervical spinal cord[1,2]. The diagnosis of ACSCI is mainly according to histories of traumas and relevant imaging examinations, including computed tomography (CT) and magnetic resonance imaging (MRI)[3]. CT can confirm clearly the presence of fracture, dislocation, hyperplastic osteophyte and ossification of posterior longitudinal ligament and so on. MRI has a better development effect on soft tissues and delivers great image of the degree of spinal cord compression and change of signal. The commonly occurrence of T2 weighted image with increased signal intensity (ISI) of

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spinal cord reflects the acute changes of nonspecific edema of spinal cord, inflammatory response and ischemia, while T1 weighted image with low signal intensity (LSI) of spinal cord presents rarely[4,5]. However, morphological imaging of routine MRI can only show the anatomic form and pressure degree of spinal cord but cannot accurately evaluate the state of the neurological function of spinal cord[6,7].

Diffusion tensor imaging (DTI) is a new technology of diffusion MRI, which quantifies diffusion movement from multiple directions by using the theory of the presence of anisotropy in diffusion of water molecule in tissues to reflect the change of fine structure and function of living tissues. The assessment parameters of DTI include apparent diffusion coefficient and fractional anisotropy (FA). The diffusion direction and speed of water molecules can be used to conduct diffusion tensor tractography (DTT) to rebuild the form and course of white matter fibers in the spinal cord, which is currently the only noninvasive method to show the nerve fiber bundle of living organisms[8].

DTI has been applied in the evaluation of diagnosis and prognosis of many spinal cord lesions. Some related researches showed that the damage degree of fibre bundle of DTT is consistent with the damage degree of nerve injury in patients and the integrity of fibre bundle is positively correlated with the prognosis of patients[9,10]. Although some literatures reported that DTT could be used in acute spinal cord injury, the number of cases that are studied in these studies are insufficient and the comparison between DTT and routine MRI in the application value of ACSCI has not been reported yet[11–14]. In this research, we compare and study the function evaluation and predictive value of prognosis of routine MRI grades and DTT grades on ACSCI by enlarging the sample size so as to verify the clinical application value of DTT more accurately.

2. Materials and methods

2.1. General data

A total of 42 cases patients with traumatic ACSCI treated with surgery in our department from January 2013 to December 2014 were included and the patients with congenital cervical vertebral malformation, intraspinal tumor, cervical vertebra infection or history of cervical spine surgery were excluded. All patients received MRI and DTI examinations before surgery and signed the informed consent before examinations. The motor score, sensory score and abbreviated injury scale (AIS) of American Spinal Injury Association (ASIA) were used to evaluate the neurological function of patients before and one year after surgery, respectively.

2.2. MRI and DTI

2.2.1. Scanning process

Imaging was performed using a GE HDxt Twinspeed 3.0T dual gradient superconductor MR (Signa HDxt, GE Healthcare, Waukesha, WI, USA) and a NV-full 8-channel array coil (GE Healthcare, Waukesha, WI, USA), at a gradient strength of 40 mT/m and a switching rate of 150 mT/ms^{-1}. Sagittal and axial T_1W_I and T_2W_I scans were performed routinely. The sagittal flair-T_1W_I having the repetition time/echo time (TR/TE) of 3 200.0 ms/116.8 ms, section thickness of 3.0 mm, interlamellar spacing of 1.0 mm, field of view (FOV) of 24 × 24 mm, image matrix of 320 × 224 and number of signals averaged (NEX) of 2, the sagittal FRFSE-T_2W_I sequence having the TR/TE of 2 698.0 ms/25.8 ms, section thickness of 3.0 mm; interlamellar spacing of 1.0 mm, FOV of 240 × 240 mm, image matrix of 320 × 224 and NEX of 2, and an axial FRFSE-T_2W_I sequence having the TR/TE of 3 200.0/121.0 ms; section thickness of 4.0 mm, interlamellar spacing of 0.5 mm, bandwidth of 41.7 kHZ; FOV of 180 × 180 mm, image matrix of 288 × 224 and NEX of 4 were acquired. DTI examination was alike with the scanning positions of routine transverse view. A single-shot spin-echo echo-planar imaging sequence with b values of 1 000 s/mm^2 and gradient directions of 15 was conducted and repeated 2 times; The TR/TE was 8 000.0/87.6 ms; section thickness was 4.0 mm; interlamellar spacing was 0.0 mm; bandwidth was 250 kHZ; FOV was 180 × 180 mm; image matrix was 130 × 128 and NEX of 2. The total DTI scan time was 5 min.

2.2.2. Image processing and DTT reestablishment

We used the GE Functool 9.4 software (GE Healthcare, Waukesha, WI, USA) to post-process the DTI data. The Correct program (included in the GE functool software) was used to correct the original data in order to reduce motion artifacts and images distortion. The transversal sections of the spinal cord at the b0 of all diffusion weighted imaging images were selected as the regions of interest for tractography using the minimal FA value of 0.2 and the maximal apparent diffusion coefficient value of 0.01.

2.2.3. Routine MRI grading and DTT grading

MRI grading and DTT grading were performed by two intermediate and senior radiologists respectively who were blinded to the clinical data during image processing and grading independently. The inconsistent grading of the final result summaries was confirmed by the two radiologists.

Patients were divided into three grades according to the severity of spinal cord compression, form and signal changes of the sagittal in routine MRI. Grade 1 had no static compression on spinal cord (no abnormal signals on sagittal T_1W_I and T_2W_I); Grade 2 had compression on spinal cord (ISI on sagittal T_2W_I but normal signal on sagittal T_1W_I); and Grade 3 had obvious compression on spinal cord (ISI on sagittal T_2W_I and LSI on sagittal T_1W_I) (Figure 1). DTT images were also divided into three grades according to the severity of the spinal cord compression and continuous degree of the fiber bundle. Grade 1 had a mixed signal in lesion area but had a complete and continuous fibre bundle; Grade 2 had abnormal signal and disordered fiber bundle in local lesion of spinal cord; and Grade 3 of DTT showed interrupted fiber bundle (Figure 2).

2.3. Statistical analysis

Data were expressed as mean ± SD and were statistically analyzed by using SPSS 18.0 software (IBM, Armonk, NY, USA). Correlations between the MRI and DTT grading and the motor scores, sensory scores and impairment scale of ASIA were analyzed by using the Spearman's rank correlation coefficient. $P < 0.05$ was considered as statistical significant.

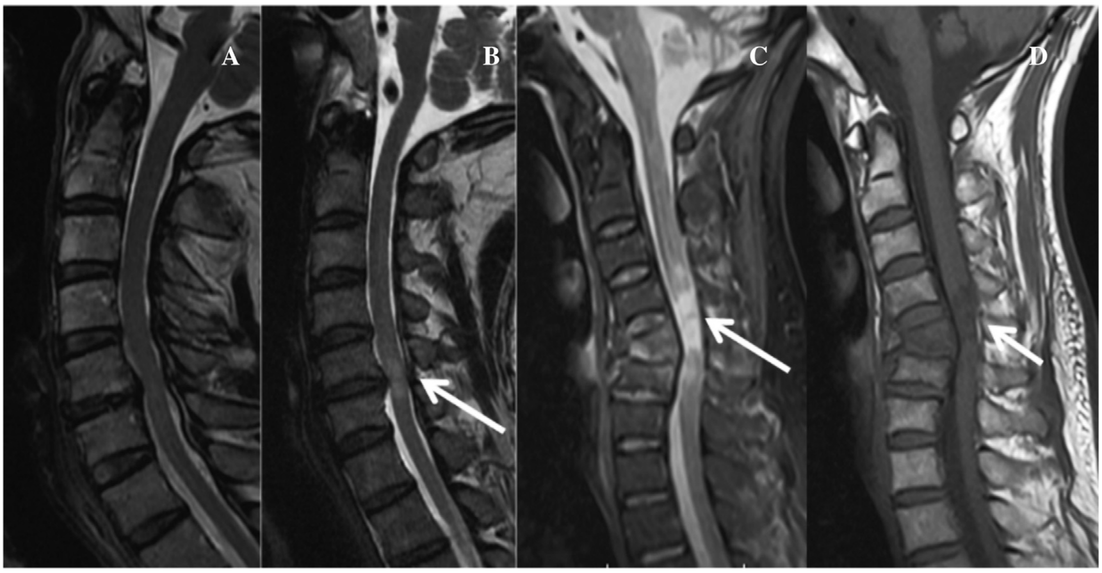

Figure 1. Signal grading of MRI.
A: Grade 1 with normal signals on sagittal T_1W_I and T_2W_I; B: Grade 2 with ISI on sagittal T_2W_I (long arrow); C: Grade 3 with ISI on sagittal T_2W_I (long arrow); D: Grade 3 with LSI on sagittal T_1W_I (short arrow).

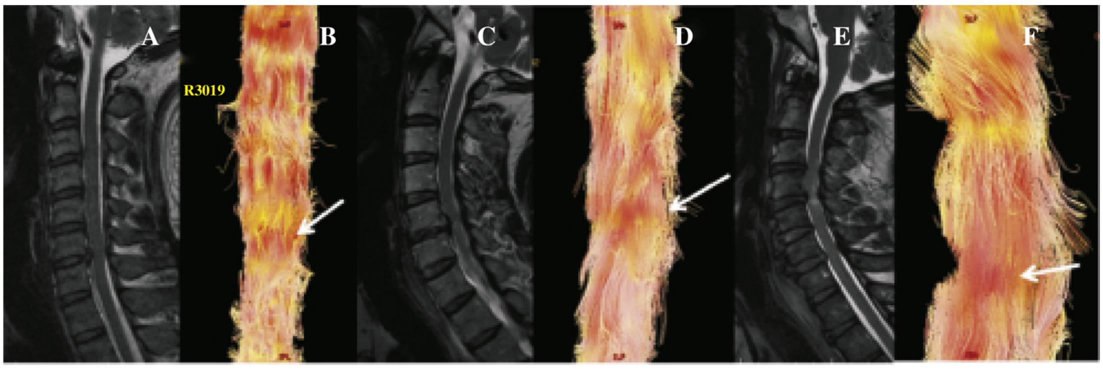

Figure 2. DTI grading.
A and B: Grade 1 with a mixed signal in lesion area but a complete and continuous fibre bundle (arrow in B); C and D: Grade 2 with abnormal signal and disordered fiber bundle in local lesion of spinal cord (arrow in D); E and F: Grade 3 with DTT showing interrupted fiber bundle (arrow in F).

3. Results

3.1. Clinical data

In patients' group, 7 cases patients with congenital cervical spine deformity, infection such as rheumatoid arthritis and tuberculosis, or history of cervical spine surgery were excluded, so that 35 patient cases with various mild or moderate spinal cord injury were collected eventually, which included 18 cases of hyperextension injury in the middle of cervical vertebra, 9 cases injured by a crashing object and 8 cases of whiplash injury caused by traffic accidents. All the patients included 21 male cases and 14 female cases ranging 42–69 years old and their mean age was 57.2 years. Table 1 shows the condition of routine MRI grading and DTT grading in patients.

3.2. Comparison of the correlation between MRI grading, DTT grading and ASIA score before and after surgery

As shown in Table 1, there were no correlations between MRI grading and motor score, sensory score and AIS of patients with ACSCI before and after surgery.

Table 1
Spearman's rank correlation coefficient between MRI grading, DTT grading and ASIA score before and after surgery.

Parameters	MRI grading	DTT grading
Motor score before surgery	0.204	–0.267
Sensory score before surgery	0.256	0.305
ASI before surgery	0.302	0.475[a]
Motor score after surgery	0.236	0.492[b]
Sensory score after surgery	0.298	0.476[a]
ASI after surgery	0.342	–0.529[b]

[a]: $P < 0.05$; [b]: $P < 0.01$.

As shown in Table 1, DTT grading was no related with motor score, sensory score before surgery but was related with AIS before surgery. DTT grading was all related with motor score, sensory score and AIS after surgery.

4. Discussion

ACSCI is mostly caused by trauma and is divided into 4 classes according to the severity of injury[15,16]. The first one is spinal cord transaction or breaking which can be found in serious spinal fracture dislocation, penetrating wound of canalis spinalis and so on, and its case fatality rate is higher and is relatively infrequent. The second is complete spinal cord injury. Although this spinal cord injury is continuous on the dissection of spinal cord, its clinical manifestation is referred to complete paraplegia due to the complete deficiency of conducting function. The third is incomplete spinal cord injury. Although this spinal cord injury is continuous on the dissection of spinal cord, its clinical manifestation is referred to incomplete paraplegia because the injury itself is relatively light and the conducting function is partly deficient including central spinal cord injury, anterior spinal cord injury, posterior spinal cord injury and brown sequard syndrome according to different injury sections which are commonly seen in clinic. And the last is cord concussion. That is the slightest spinal cord injury and its clinical manifestation is referred to incomplete paraplegia, and its symptoms and signs will commonly disappear within 1–2 days after injury and this type will rarely leave sequelae for the nervous system.

The diagnosis of ACSCI is mainly based on medical histories and image examinations currently. MRI is also necessary, which can show the condition of spinal cord compression and the change of spinal cord signal[3]. Some researches showed that ISI of spinal cord MRI has a clear correlation with the degrees and prognosis of spinal cord injury[17–20], while some scholars oppose to this view[21]. Some studies showed that nerve injury will be severer and the prognosis becomes poorer as the ISI on sagittal T_2W_I and LSI on sagittal T_1W_I appear in cervical cord[22–24]. Hence, we synthesized the change of ISI on sagittal T_2W_I and sagittal T_1W_I in cervical spinal cord and graded them.

DTI is a new technology developing on the basis of diffusion weighted imaging, which can reflect the change of the fine structure and function of living tissues and show three-dimensional morphological change of white matter fiber tracts by using DTT. Demir *et al.* firstly reported that DTI had a higher sensibility on the diagnosis of chronic spinal cord injury than routine MRI and DTI can find the change of microscopic pathology in spinal cord before nothing abnormal detected on MRI[25]. Hereafter, several studies have also confirmed that DTI can quantitatively evaluate the functional status of spinal cord and has a higher predictive value on the diagnosis and prognosis than routine MRI[26–28].

The research on the correlation between DTT and the neurological function of chronic spinal cord injury before operation and the prognosis after operation shows that the damage degree of fibre bundle is consistent with the damage degree of the nerve function in patients and the integrity of fibre bundle is positively correlated with the prognosis of patients[23,29–31]. The more complete DTT fibre bundle was, the better improvement of the neurological function in patients and patients with interrupted DTT fibre bundle receive poor prognosis. Therefore, we conducted a classification according to the integrity degree of DTT fiber bundle. Although some literatures reported that DTT could be used in acute spinal cord injury, the number of cases that are studied in those studies are insufficient and the comparison between DTT and routine MRI in the application value of ACSCI has not been reported yet. In order to verify the functional evaluation and predictive value of prognosis of DTT grading on ACSCI more accurately, we enlarged the sample size and collected 35 cases with ACSCI to perform DTI and DTT fiber bundle tracer.

The results showed that DTT grading has a higher correlation with ASIA score before surgery, compared with MRI grading and had a clearly correlation with the prognosis of patients, which is consistence with the previous results of DTT research in chronic spinal cord injury[23,29–31]. Routine MRI can only reflect the anatomically morphologic change of spinal cord, but it is unable to accurately display the state of spinal function. However, DTT traces fibre bundle according to the FA value belonging functional imaging. Hence, DTT can assess the functional status of spinal cord more accurately in theory and our results also confirmed that. Certainly, DTT is just a reconstruction technology of computer based on setting FA values, after all. When the FA value is less than the set minimum value, fibre bundle is unable to display. Hence, the reconstructed fibre bundle cannot fully represent the real structure of the spinal cord and the tracer technique cannot show the change of microcirculation around spinal cord injury and the growth of gliocyte and what extent it can reflect the real pathology of spinal cord remains to be further studied.

In addition, there are many causes influencing the prognosis of ACSCI, including age of patients, occurrence time, preoperative functional status, segmental lesions, operation methods, rehabilitation training, *etc.*[32,33]. We just simply compared the diagnosis and predictive prognosis value of two imaging methods in this research, hence, while the evaluation and prognosis of ACSCI still need a comprehensive consideration in clinic.

Conflict of interest statement

The authors report no conflict of interest.

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