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Clinical Study

The diagnosis of double-crush lesion in the L5 lumbar nerve using diffusion tensor imaging

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Abstract

BACKGROUND CONTEXT: A double-crush lesion is a condition in which the lumbar nerve is compressed both medially and laterally in the spinal canal, where diagnosis can be very difficult, and is a factor leading to poor surgical success rates.

PURPOSE: Diffusion tensor imaging (DTI) was used to determine DTI parameter fractional anisotropy (FA) values and apparent diffusion coefficient (ADC) in both intraspinal column lesions alone and in double-crush lesions.

STUDY DESIGN: This study used a prospective study.

PATIENT SAMPLE: Of the 56 cases (mean age: 72.2 years) that underwent laminectomy for lumbar spinal stenosis at our clinic between April 2013 to March, 2015, 10 cases with L5 radiculopathy caused by L4–L5 stenosis (Intraspinal stenosis group (Group I); mean age: 74.7 years), and 5 cases with persistent symptoms caused by L5 foraminal stenosis despite L4–L5 decompression surgery (Double-crush group (Group D); mean age: 77.6 years) were targeted. One patient in Group D was diagnosed through microendoscopic intrapedicular partial pediculotomy and the remaining four cases by nerve root infiltration. Five healthy cases (mean age: 54 years) were studied as controls.

OUTCOME MEASURES: Intraspinal zone (Iz), nerve root (N), and extraforaminal zone (Ez) were established as the regions of interest, and the L5 nerve FA and ADC values were determined on the affected side.

METHODS: Diffusion tensor imaging was performed prospectively by 1.5T magnetic resonance imaging before surgery, and DTI parameters of L5 nerve were evaluated in all patients and healthy volunteers. Student *t* test was used for group comparisons, and a $p<.05$ was considered statistically significant.

FDA device/drug status: Not applicable.

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We declare that all human and animal studies have been approved by the Chiba University and Shimoshizu National Hospital and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. We declare that all patients gave informed consent before inclusion in this study.

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RESULTS: Fractional anisotropy values (Iz, N, Ez) were 0.415, 0.448, and 0.517, respectively, increasing as sites became more distal. Group I values were 0.335, 0.393, and 0.484, and Group D values were 0.296, 0.367, and 0.360. Compared with the healthy volunteers, Group D had significantly lower Iz ($p<.05$) and Ez ($p<.001$) values, while Group I had significantly lower Iz ($p<.05$) values. In Group D, Ez FA values were significantly lower ($p<.001$) than in Group I. Apparent diffusion coefficient values (Iz, N, Ez) in the healthy control group were 1.270 mm^2/s, 1.151 mm^2/s, and 0.937 mm^2/s with values decreasing as sites grew distal. In Group I, the ADC values were 1.406 mm^2/s, 1.184 mm^2/s, and 1.001 mm^2/s, while in Group D they were 1.551 mm^2/s, 1.412 mm^2/s, and 1.329 mm^2/s. Compared with the healthy volunteers, Iz ($p<.05$) and Ez ($p<.05$) values were significantly higher in Group D. The N ($p<.01$) and Ez ($p<.001$) ADC values were significantly higher in Group D than in Group I.

CONCLUSIONS: Depending on where the nerve was compressed, changes in DTI parameters revealed nerve damage (low FA values and increased ADC) in the intraspinal canal in the Intraspinal Group, and over a widespread area in the Double-crush Group spanning the medial to lateral spinal canal. Our research suggests that in cases where double crush is suspected before surgery, failed back surgery syndrome may be prevented by evaluating DTI images. © 2016 Elsevier Inc. All rights reserved.

Keywords: Apparent diffusion coefficient; Diffusion tensor imaging; Double-crush lesion; Fractional anisotropy; Lumbar foraminal stenosis; Lumbar spinal stenosis

Introduction

Lumbar foraminal stenosis is a condition in which a nerve root or spinal nerve is entrapped in a narrowed lumbar foramen in degenerative lumbar spinal disorders. There is a dorsal root ganglion that functions as a pain receptor at this site and so this condition is refractory and can cause severe lower limb pain [1]. However, Macnab et al. [2] suitably referred to this region as the "hidden zone," and despite major strides in imaging technology today, this site is still often overlooked and can be a factor that negatively impacts surgical success rates.

Nerve decompression sites differ in intraspinal lesions and foraminal stenosis, and it has been reported that many cases of failed back surgery syndrome are caused by inappropriate treatment of foraminal stenosis [3]. Conditions that cause L5 radiculopathy include when the L4–L5 level is compressed by an intraspinal canal lesion and a lateral lesion presses against the L5–S1 level so that the nerve is compressed at two levels (medial and lateral), and this is called a double-crush lesion. However, traditional imaging studies do not allow the clinician to differentially diagnose whether the compressing lesion in inside or outside the spinal canal, or if a double-crush lesion is responsible.

Diffusion weighted images (DWIs) are created by using magnetic resonance imaging (MRI) to enhance water molecule movements (diffusion) which are then imaged. They can be made by applying a motion problem gradient (MPG) from one direction to proton diffusion movement [4–7]. Diffusion weighted images are essential in the diagnosis of acute cerebral infarctions [8], and this technology is now widely used in clinical practice [9,10]. Diffusion weighted image not only affects the diffusion of water molecules but also has a strong influence on the directionality of the diffusion. In nerve fibers, it prevents axon cellular membrane and myelin sheaths from diffusing in directions perpendicular to nerve fibers, so water molecule isotropy is lost. This condition is referred to as anisotropy and selective recording of this data is called diffusion tensor imaging (DTI) and tractography. Indicators of anisotropy include fractional anisotropy (FA) which ranges in value from 0 to 1. As it approaches 1, the anisotropy-enhanced condition grows stronger, while 0 means that it is completely isotropic. Recently, DTI has been reported to be useful in demyelinating diseases such as multiple sclerosis or chronic peripheral nerve compression lesions such carpal tunnel syndrome [11,12]. Myelinated nerves in tissue myelin sheath can restrict water molecule diffusion to run parallel to the nerve fiber, and presents with potent anisotropy, but demyelination that accompanies nerve injury such as spinal injuries can reduce the anisotropy, and decreased FA values have been reported in such cases [13,14].

We previously reported that in patients with lumbar foraminal stenosis, the tract was blocked at the stenotic site and FA values were low [15]. Diffusion tensor imaging was used to investigate DTI parameter such as FA and apparent diffusion coefficient (ADC) values in double-crush lesions, and our findings are presented below.

Materials and methods

Of the 56 cases (mean age: 72.2 years) who underwent laminectomy for spinal canal stenosis at our clinic between April 2013 to March, 2015, 10 cases with L5 radiculopathy caused by L4–L5 stenosis (Intraspinal stenosis group (Group I); mean age: 74.7 years), and 5 cases with persistent symptoms caused by L5 foraminal stenosis despite L4–L5 decompression surgery (Double-crush Group (Group D; mean age: 77.6 years) became the subjects of this study. Five healthy cases (mean age: 54 years) were also studied as the control group. In Group I, the only medial stenosis at the L4–L5 level without L5 foraminal stenosis was seen on computed tomography (CT) and MRI. On the other hand, in Group D, although

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