ORIGINAL CONTRIBUTION

Serial Changes on MR Imaging of Herniated Lumbar Discs Treated by Percutaneous Laser Nucleotomy : Correlation with Early Clinical Results

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Percutaneous Laser Nucleotomy (PLN) is a new treatment for disc herniation applying neodymium : yttrium-aluminum-garnet (Nd : YAG) laser through inserted needle into the center of the disc, with less invasion and shorter hospitalization than conventional open surgery. Serial MR images were observed in 21 patients before and after PLN. Canal occupying ratio (COR) and signal intensity (S.I.) of herniated disc were measured. Recovery rate of symptoms was 57.2%, based on scoring system proposed by the Japanese Orthopaedic Association for low-back pain (JOA score). The successful group ($\geqq$30% improvement in JOA score) showed rapid decrease in signal intensity, though the ineffective group ($<$30% improvement in JOA score) showed unchanged intensity on T_2-weighted sequence. Increase of signal intensity was observed in some patients whose symptoms had become worse. This may correlate with increase of water content and inner pressure on the disc. There was no significant difference between pre- and post-COR ; however, more than 10% COR decrease was observed in 7 patients and symptoms improved in these cases. Thus the prognosis of the patients treated with PLN can be assessed by MR findings.

INTRODUCTION

The patients with lumbar disc herniation resistant to conservative therapy, such as activity modification, bracing, pelvic traction, and/or medication, are usually subjected to open surgeries to remove herniated masses; however, it takes 2–3 months of hospitalization and rehabilitation. To reduce the burden on patients, a variety of percutaneous procedures, termed intradiscal therapy, have been developed, such as chemonucleolysis with chymopapain[1)] and per-

Keywords Disc herniation, MRI, Lasers, Percutaneous Laser Nucleotomy

cutaneous nucleotomy with cutter and suction[2)~8)].

As laser technique was introduced to intradiscal therapy[9)], we have been experimentally studying a new technique named Percutaneous Laser Nucleotomy (PLN) using neodymium : yttrium-aluminum-garnet (Nd : YAG) laser since 1986[10)], and began clinical application in 1992 to treat symptomatic lumbar disc herniation. A needle was inserted into the center of the disc which was irradiated with a laser. The concept of PLN technique is reduce intradiscal pressure by the action of thermal energy from the laser[11)~13)].

We report here serial MRI appearances of herniated discs before and after PLN, and present the early clinical results of our study, correlating various MR imaging findings with clinical outcome.

METHODS

Subjects

The subjects of this study were 21 patients with herniated lumbar discs (14 males and 7 females, ranged from 16 to 62 years with a mean of 26.3 years), including 6 patients followed up with open surgery after PLN. All the patients were resistant to conservative therapies for at least 6 weeks. Levels of responsible disc, determined by neurological examination, myerography/myelo-CT and MR imaging, was L4/5 in 11 patients, L5/6 in 2 patients and L5/S in 8 patients. The type of herniation was diagnosed as follows : protrusion (Pr) in 4 patients, subligamentous extrusion (Es) in 10 patients and transligamentous extrusion (Et) in 7 patients. There were no patients with sequestration (Sq) nor with previous disc surgery. Informed consent was obtained from each patient prior to treatment.

Laser intervention

An instrument consisting of double-lumen needle, guide pin, bare quartz fiber and laser source (Osada YAG N-40 ; Osada Electric Co. Tokyo, Japan) was used (Fig. 1). The guide pin was inserted percutaneously into the center of the disc with local anesthesia under biplanar fluoroscopic guidance. The outer needle (1.5 mm diameter) was set into the same position through the guide pin. After removal of the guide pin, the inner needle including a bare laser fiber was fixed into the outer needle. Ten Watts, 0.3 second pulses of Nd : YAG laser (wavelength 1064 nm) were radiated repeatedly at 1.7 second intervals until the total energy reached approximately 1500 Joules[10)]. The double-lumen needle made it possible to suck out fragment tissues and gas produced by the laser intervention.

MR imaging

MR spin-echo imaging was carried out on a Signa 1.5-T superconducting system (G. E. Medical Systems. Milwaukee, Wis, USA) with

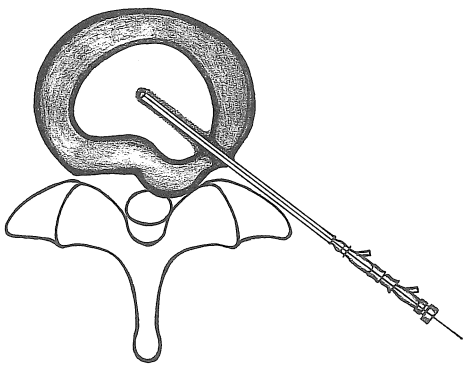

Fig. 1. The schema of PLN.

Recived Feb. 23, 1996 ; reveised Apr. 15, 1996
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a surface coil for thoracolumbar spine examination. T_1-weighted (TR=500 ms, TE=20 ms) and T_2-weighted (TR/TE=2000/80) sagittal images, and T_1-weighted (TR/TE=500/20) axial oblique images parallel to each disc were obtained with a 5 mm slice thickness. The disc herniation was estimated with respect to size and hydration status on MR images by 4 radiologists. MR imaging and clinical outcome were evaluated repeatedly ; before PLN, after 1 month, 3 months, 6 months and 12 months. Six of the patients on whom treatment had failed were subsequently treated by either laminectomy or discectomy ; they were not followed up. The size of the herniated mass was measured as a percentage of the anteroposterior diameter of the spinal canal (COR) on axial T_1-weighted image (Fig. 2). The signal intensity (S.I.) of the disc with herniation was measured by at the regions of interest (ROI) on mid-sagittal T_2-weighted image (Fig. 3). ROI was encircled just along the margin of the disc. The area of the disc on mid-sagittal T_2-weighted image, which was indicated at the same time as ROI measurement, was recorded as reference data. To avoid fluctuations of signal intensity in the successive MR imagings on the same patient, we estimated the mean signal intensities of the upper and lower lumbar vertebral bodies, interposing the target disc, as controls, made correction of back ground noises, and calculated S.I. ratio.

S.I. ratio=a/b
a=(S.I. of the herniated disc)
−(S.I. of background noise)
b=(mean S.I. of vertebra)
−(S.I. of background noise)

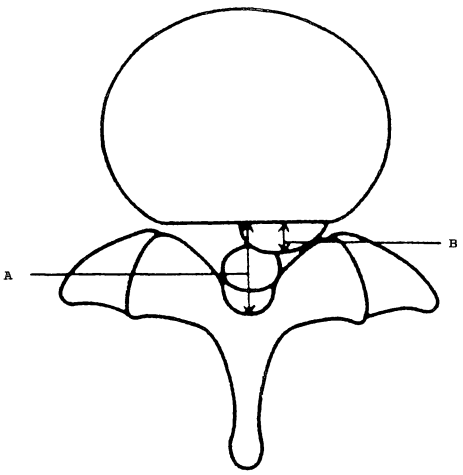


Fig. 2. Measurement of COR. Percentage of the size of herniated mass (B) to the anteroposterior diameter of the spinal canal (A) was calculated. COR=B/A×100

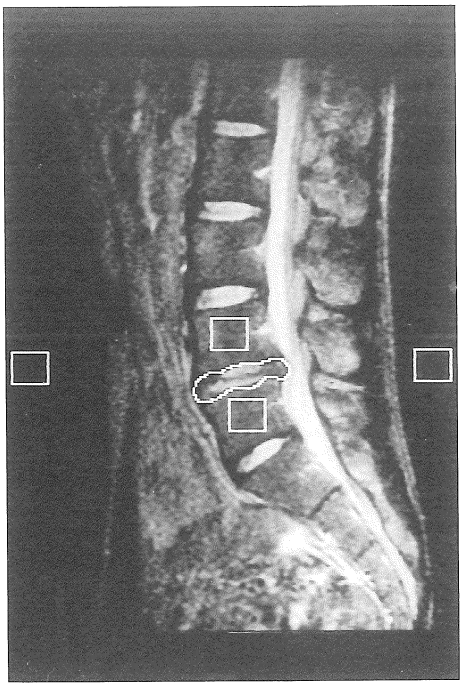


Fig. 3. Measurement of ROI. ROI was enclosed just around the objective intevertebral disc. ROIs of near the center of both upper and lower vertebral bodies interposing the disc, and background noise were added to S.I. correction.

Each value of before PLN (COR, area of the disc and S.I. ratio) was considered as 100 and variations were observed.

Evaluation of clinical outcome

Clinical outcome was evaluated according to modified scoring system proposed by the Japanese Orthopaedic Association for low-back pain (JOA score) with a maximum of 15 points consisting of subjective symptoms and clinical signs (Table 1), at the same time as MR imagings and one week after PLN additionally. Recovery rate on JOA score was calculated.

Recovery rate = c/d × 100 (%)
c = (post-PLN JOA score)
− (pre-PLN JOA score)
d = 15 − (pre-PLN JOA score)

A Recovery rate of more than 30% at the latest assessment was considered to be successful. According to the latest recovery rate after PLN, the patients were divided into 3 groups as follows ; successful without anodyne medication (group A), satisfactory with anodyne medication (group B) and ineffective (group C).

Statistical analysis

All the serial results were expressed with mean±SD and compared using Student's t-test.

RESULTS

All the procedures of PLN were completed within about 60 minutes. All the patients were allowed to ambulate with soft braces after one-

Table 1. Part of Scoring System Proposed by the Japanese Orthopaedic Association in Assessment of Treatment for Low-back Pain (JOA score)

1. Subjective Symptoms (9 points)
   A. Low back pain
      None (3), occasional mild pain (2), frequent mild or occasional severe pain (1), frequent or continuous severe pain (0)
   B. Leg pain and/or tingling
      None (3), occasional slight symptoms (2), frequent slight or occasional severe symptoms (1), frequent or continuous severe symptoms (0)
   C. Gait
      Normal (3), able to walk farther than 500 m although it results in pain, tingling, and/or muscle weakness (2), unable to walk farther than 500 m owing to leg pain and/or muscle weakness (1), unable to walk farther than 100 m owing to leg pain and/or muscle weakness (0)
2. Clinical signs (6 points)
   A. Straight-leg raising test (including tight hamstrings)
      Nomal (2), 30–70 degrees (1), less than 30 degrees (0)
   B. Sensory disturbance
      None (2), slight disturbance (not subjective) (1), marked disturbance (0)
   C. Motor disturbance (MMT*)
      Normal (Grade 5) (2), slight weakness (Grade 4) (1), marked weakness (GRADE 3–0) (0)

* MMT : manual muscle testing. Grade 5 (normal, 100%) ; Grade 4 (good, 75%), Grade 3 (fair, 50%) ; Grade 2 (poor, 25%) ; Grade 1 (trace, 10%) ; Grade 0 (0%)

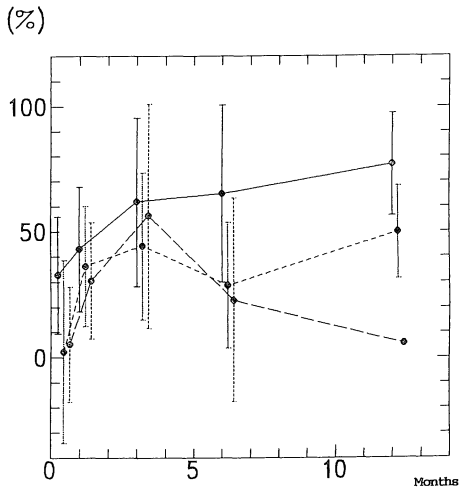


Fig. 4. Change of JOA score

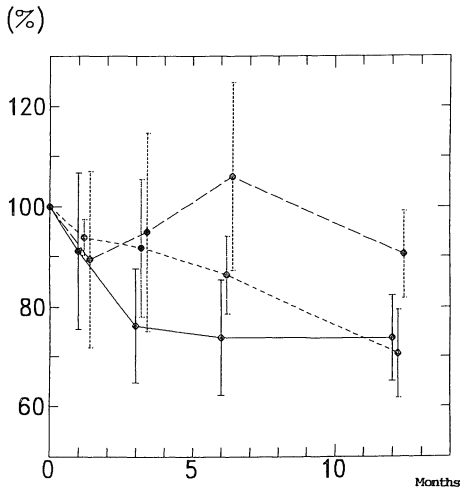


Fig. 5. Change of S.I.

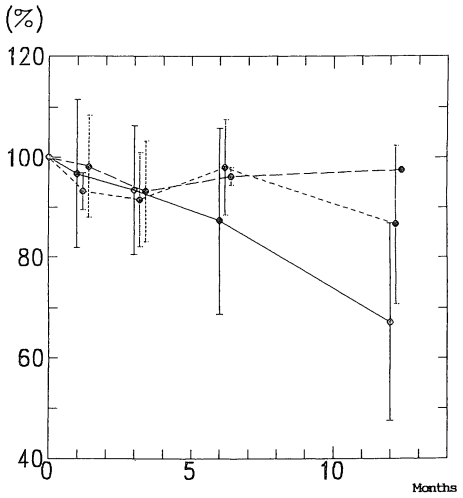


Fig. 6. Change of COR

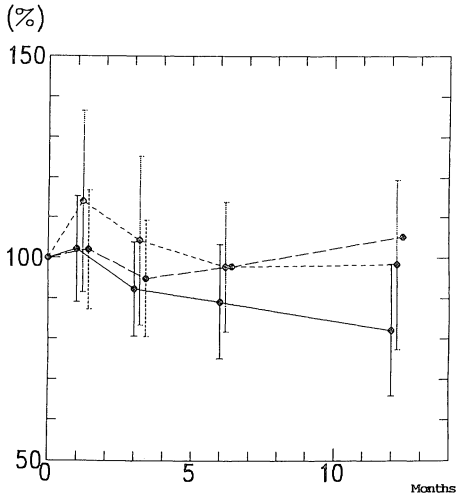
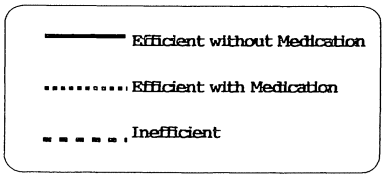


Fig. 7. Change of disc area



day bed rest and could leave hospital 5–6 days after PLN. There were no complications associated with PLN.

PLN was successful in 12 patients out of the total 21 (57.2%) ; 7 patients (5 males and 2 females ; 3 Pr, 3 Es and 1 Et ; 6 L4/5 and 1 L5/6) in group A, and 5 patients (3 males and 2 females ; 2 Es and 3 Et ; 4 L4/5 and 1 L5/S) in

group B. Nine patients (6 males and 3 females ; 1 Pr, 5 Es and 3 Et ; 2 L4/5, 1 L5/6 and 6 L5/S) whose recovery rates were below 30%, including 6 patients (4 males and 2 females ; 1 Pr, 2 Es and 3 Et ; 1 L4/5, 1 L5/6 and 4 L5/S) who underwent open surgery after PLN because they showed poor improvement of symptoms, were considered as group C.

Recovery rate by JOA score (Fig. 4) generally improved ; however, the majority of successful patients (group A) showed a gradual relief of symptoms by the first week and symptomatic improvement until 12 months after PLN. Group B and C had a tendency to get worse after six months, though patients in group B were well controlled using anodyne.

Table 2. Results in Group A (Efficient without Medication)

	1 W	1 M	3 M	6 M	12 M
Recovery rate of JOA score	37.2±23.2 P<0.01	93.1±24.7 P<0.01	61.9±35.3 P<0.01	65.2±35.3 P<0.01	76.7±20.5 P<0.01
Change of S.I.		91.1±15.6 NS	76.2±11.4 P<0.01	73.8±11.6 P<0.01	73.7± 8.4 P<0.01
Change of COR		96.7±14.8 NS	93.4±12.9 NS	87.3±18.5 NS	67.2±19.6 NS
Change of disc area		102.2±13.0 NS	92.3±11.7 NS	89.2±14.1 NS	82.2±16.3 NS

Table 3. Results in Group B (Efficient with Medication)

	1 W	1 M	3 M	6 M	12 M
Recovery rate of JOA score	2.2±36.4 NS	36.3±23.9 P<0.05	44.3±29.1 P<0.05	28.7±24.9 NS	49.8±18.5 P<0.01
Change of S.I.		93.8± 3.6 P<0.01	91.8±13.7 NS	86.4± 7.7 P<0.01	70.6± 8.9 P<0.01
Change of COR		93.2± 3.7 P<0.01	91.5± 9.4 NS	98.0± 9.5 NS	86.6±15.8 NS
Change of disc area		114.0±22.4 NS	104.3±20.9 NS	97.8±16.0 NS	98.4±21.0 NS

Table 4. Results in Group C (Inefficient)

	1 W	1 M	3 M	6 M	12 M
Recovery rate of JOA score	5.2±22.9 NS	30.5±23.1 P<0.05	56.3±44.6 P<0.05	22.9±40.5 NS	5.6±7.9 NS
Change of S.I.		89.4±17.6 NS	94.9±19.8 NS	106.0±18.7 NS	90.5±8.5 NS
Change of COR		98.1±10.2 NS	93.2±10.1 NS	96.2± 1.8 NS	97.5±0.3 NS
Change of disc area		102.2±14.7 NS	94.9±14.4 NS	97.9± 2.4 NS	105.3±6.8 NS

Signal intensity of the treated discs on T_2-weighted images (Fig. 5) decreased in general. Especially, the decrease was quite sharp in group A. On the other hand, that of group C showed little change.

On the point of COR (Fig. 6), there were 7 cases whose COR decreased more than 10% and they all experienced relief of symptoms. The result of change of the disc area (Fig. 7) was almost the same as that of COR.

Each serial change in the result of statistical difference is shown in table 2–4.

MR imaging appearances were suggestive of clinical prognosis (Case 1–3) (Fig. 8–10).

Case 1. (Fig. 8)

A 46-year-old female, L4/5 level, Pr type, effective without medication (group A)

Signal intensity have decreased since 3 months after PLN, and the hearniated mass disappeared at 12 months after PLN. Decrease of signal intensity and herniated mass have much to do with successful results.

Case 2. (Fig. 9)

A 28-year-old female, L4/5 level, Es type, effec-

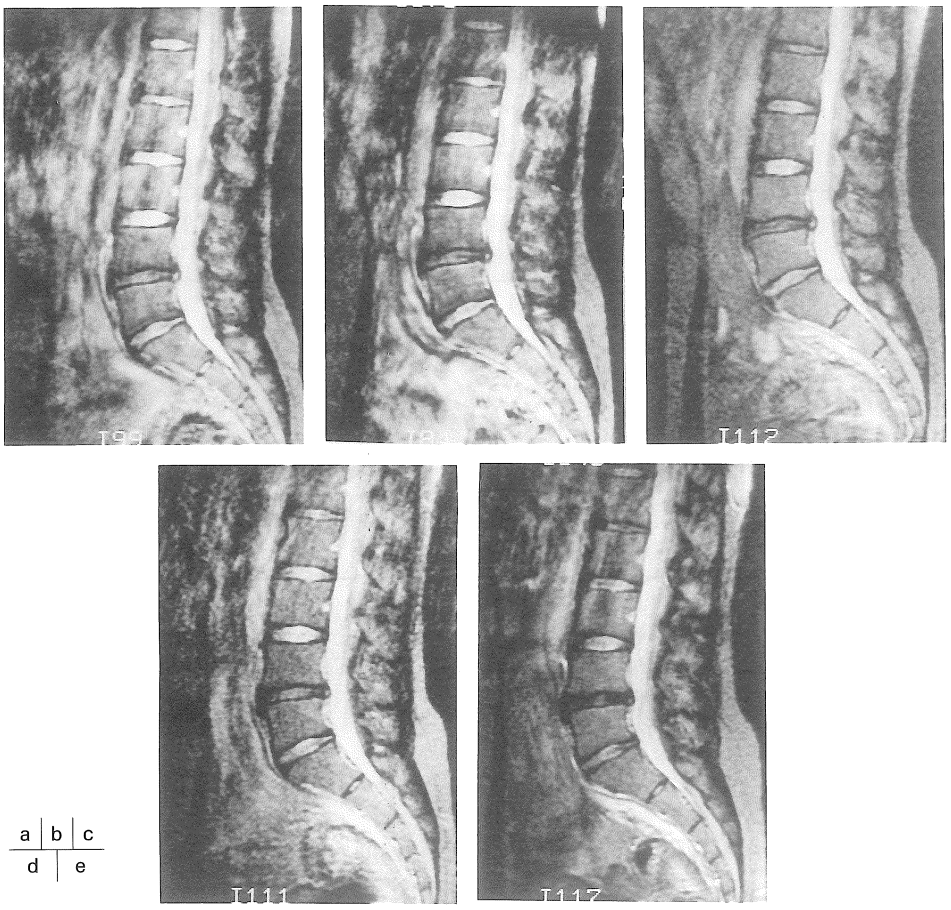


Fig. 8. A Case of group A (a) pre-PLN, (b) 1 month after PLN, (c) 3 months after PLN, (d) 6 months after PLN, (e) 12 months after PLN

tive with medication (group B)

She got worse in symptoms at 6 months after PLN. Mild re-increase in signal intensity of the disc and enlargement of COR were observed almost coincidently. She improved gradually by 12 months after PLN, then signal intensity and COR decreased. Clinical outcomes were almost parallel to MR findings.

Case 3. (Fig. 10)

A 24-year-old male, L5/S level, Es type, ineffective (group C)

Though he was under good controll untill 6 months after PLN, he got worse at 12 months after PLN and was decided to be ineffective at the latest clinical judgement. Signal intensiry re-increased at 3 and 6 months after PLN, however, that at 1 month after PLN decreased as compared to that at pre-PLN. Hernia mass got larger gradually after 3 months, especially at 12 months after PLN.

DISCUSSION

Percutaneous procedures to the interver-

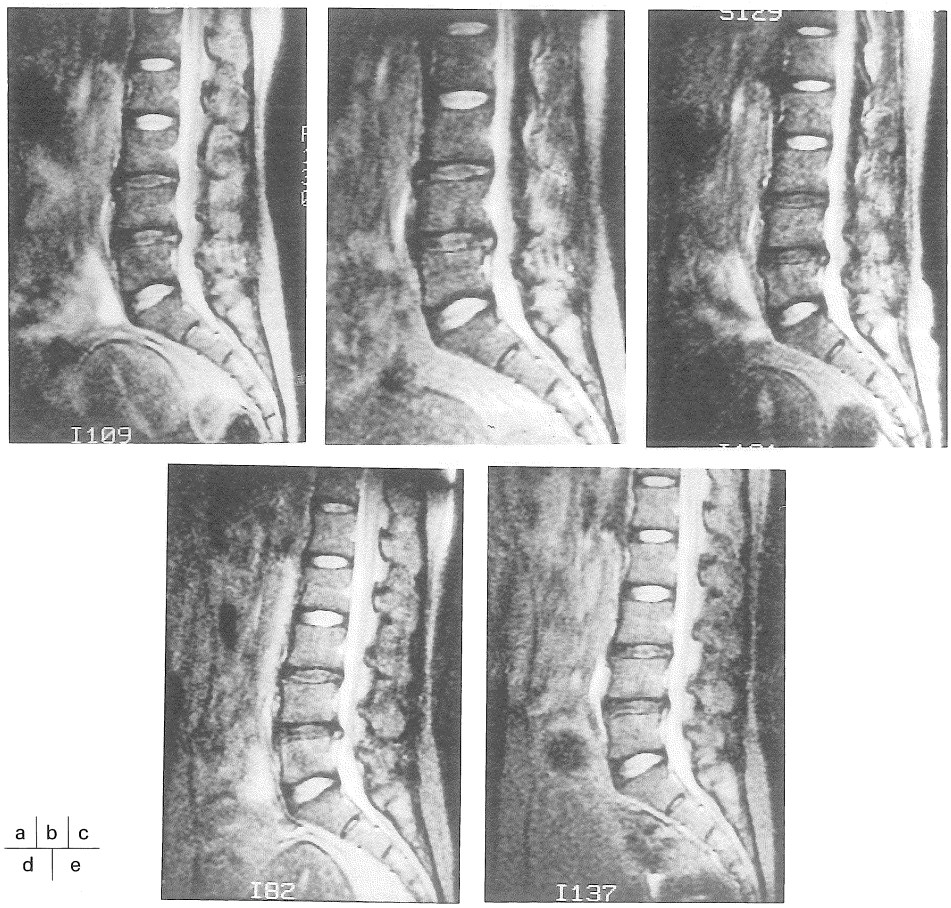


Fig. 9. A Case of group B (a) pre-PLN, (b) 1 month after PLN, (c) 3 months after PLN, (d) 6 months after PLN, (e) 12 months after PLN

tebral discs could be carried out under local anesthesia, thus avoiding postoperative adhesions around the spinal nerve roots or dural sac. Moreover it could shorten hospitalization and rehabilitation periods. A variety of percutaneous procedures have been developed by some clinicians and satisfactory clinical results have been reported[1)~8)]. Since 1986, we have experimented with PLN using the Nd : YAG laser[10)] and began clinical application in 1992 at Osaka Medical College to treat symptomatic lumbar disc herniation. The Nd : YAG laser has a wavelength of 1064 nm, and its energy in the near infrared spectrum is minimally absorbed by water, indicating efficiency for tissue coagulation[12)~15)].

In this study, we compared MR images obtained before and after PLN serially and exa-

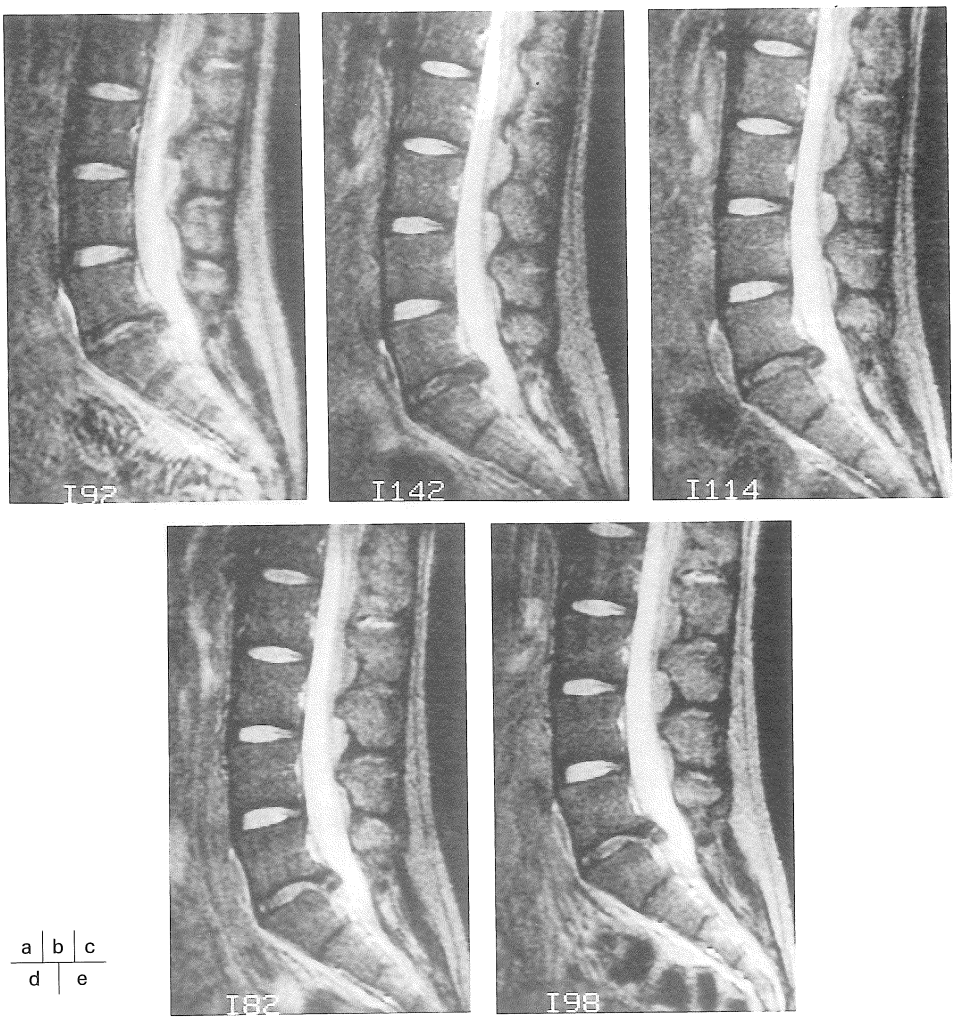


Fig. 10. A Case of group C (a) pre-PLN, (b) 1 month after PLN, (c) 3 months after PLN, (d) 6 months after PLN, (e) 12 months after PLN

mined the correlation between MR imaging appearances and clinical outcome. MR imaging enables a quantification of disc degeneration in terms of hydration level according to the signal intensity on T_2-weighted images noninvasively[12)~16)]. Decrease in the signal intensity of the disc was thought to be caused by dehydration of the cartilaginous matrix resulting from coagulation and the following scar formation, and that finding was observed especially in the efficient cases. Diminution of peripheral herniated mass probably occurs in the central area of disc contract in the process of scar formation[16),17)]. More than 10% decrease of COR was observed in 7 cases with satisfactory results, thus decrease in size of herniation mass was considered to be related to improvement of clinical symptoms. However there was no significant difference in the measurable herniation size between the groups defined by clinical outcome. Other explanations for pain relief might occur.

Castagnera et al[18)] reported the absence of correlation between intradiscal pressure measured by discomanometry and hydration level on MR images. However dehydration of the disc should result in the reduction of intradiscal pressure due to the bulk-modules effect[11)]. The mechanism of pain relief was attributed to the specific pressure-volume dynamics of the intervertebral discs (bulk modules of elasticity) ; a small immeasurable decrease in volume of a disc could cause a great change in pressure[11)]. Some authors postulated that radiculopathy can be due to chemical irritations such as inflammatory agents and the autoimmune response of protein to the nucleus pulposus[19)~21)]. Thus the decrease of intradiscal pressure and the removal or degeneration of irritative chemicals by thermal effect might bring pain relief.

Histological effects of laser exposure of the herniated intervertebral disc were verified sequentially as follows ; vaporization of the nucleus pulposus after 1 week, the beginning of proliferation of cartilaginous cells and fibrous tissues after 3 and 4 weeks, the nearly total replacement of cartilaginous fibrous tissue after 8 weeks[10)]. Another report of the extent of laser effects mentioned irreversible change occurring at the high energy center and reversible temperature induced change occurring at the periphery[12),13)]. To use a laser safely *in vivo*, selection of appropriate energy was necessary, and it was necessary not to degenerate the whole of the intravertebral disc irreversively. We assumed that subsequent problems might result from the change occurring at the reversible zone. One explanation for a bad turn might be inflow of fluid through microscopic tears in the disc annuls, which correlate with increase of intradiscal pressure and signal intensity ; increasing pressure might widen the tear, leading to re-herniation. We speculate that re-herniation would occur when intradiscal pressure re-increases. MR imaging appearances were suggestive of clinical prognosis, including the risk of re-herniation.

In conclusion, the signal intensity change observed on MR images correlate with the clinical condition, in our limited cases and one-year follow-up.

Acknowledgements

We would like to express the sincere appreciation and hearty gratitude to Dr. Hiroyuki Asaba for his guidance and help in completing this manuscript.

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Abbreviation :
COR (canal occupying ratio)
Es (subligamentous extrusion)
Et (transligamentous extrusion)
JOA (the Japanese Orthopaedic Association)
Nd : YAG (neodymium : yttrium-aluminum-garnet)
PLN (Percutaneous Laser Nucleotomy)
Pr (protrusion)
Sq (sequestration)