Development of new surgical treatments in spinal surgery: expansive open-door laminoplasty and percutaneous nucleotomy

Kazuhiro Chiba and Yoshiaki Toyama

Department of Orthopaedic Surgery, School of Medicine, Keio University, Tokyo, Japan

(Received for publication on May 15, 2001)

Abstract. The outstanding achievements of two renowned spine surgeons, who are alumni of the Department of Orthopaedic Surgery, Keio University, are described. Anterior decompression followed by fusion and laminectomy had been the standard techniques for cervical myelopathy due to disc herniation, spondylosis and ossification of the posterior longitudinal ligament. However, both techniques were not without certain comorbidities. Dr. Kiyoshi Hirabayashi devised an epoch-making expansive open-door laminoplasty, in which both sufficient posterior decompression and preservation of cervical stability are achieved simultaneously with reduced risk of such complications. Dr. Sadahisa Hijikata is the pioneer of a totally new concept treatment, percutaneous nucleotomy, for lumbar disc herniation, one of the most prevailing diseases that cause low back pain and sciatica. He devised this technique to avoid prolonged conservative treatment with associated suffering of the patients and to minimize the chance of morbidity that is occasionally associated with an open surgery. This technique, together with chemonucleolysis, has led to the establishment of intradical or intermediate treatments which lie between conservative and surgical treatments. Both techniques have not only brought the relief of pain and suffering in numerous patients, but have also opened the door to the development of many new modified procedures and technologies. Most importantly, these two techniques still remain as the most viable choice among various similar modifications. The rationale, indictions, technique as well as the present status and future perspective for these two innovative yet fundamental techniques are introduced and discussed. (Keio J Med 50 (3): 142–151, September 2001)

Key words: spinal surgery, expansive laminoplasty, cervical myelopathy, percutaneous nucleotomy, lumbar disc herniation

Introduction

It is our great honor as well as privilege to be able to make a worthwhile contribution to the commemorative 50th volume of the Keio Journal of Medicine, one of the few English journals published by a single school. Through this journal, Keio Medical Society has continuously conveyed its brilliant scientific achievements to the medical communities outside Japan. In the present paper, we would like to introduce the accomplishments of two renowned spine surgeons who are alumni of Keio. They both developed new surgical techniques for the most common spinal disorders and furthermore has significantly contributed to the establishment of totally new concepts that formed the basis for the development of many other treatment options.

Dr. Kiyoshi Hirabayashi, former Dean of the Keio Junior College of Nursing and former Professor of the Department of Orthopaedic Surgery, Keio University, developed a novel technique "expansive open-door laminoplasty (ELAP)" which has brought remarkable improvement in the surgical results of cervical myelopathy caused by a variety of cervical disorders including disc herniation, spondylosis and ossification of the posterior longitudinal ligaments (OPLL).

Reprint requests to: Dr. Kazuhiro Chiba, Department of Orthopaedic Surgery, School of Medicine, Keio University, 35 Shinanomachi, Shinjuku-ku, Tokyo 160-8582, Japan, e-mail: kchiba@sc.itc.keio.ac.jp

Dr. Sadahisa Hijikata, Vice President of the Tokyo Den-ryoku Hospital and former Director of the Department of Orthopaedic Surgery of the same hospital invented an entirely new concept treatment, ''percutaneous nucleotomy (PN)'', for lumbar disc herniation, one of the most prevailing diseases that causes low back pain and sciatica.

Expansive Open-Door Laminoplasty

Until the late sixties, conventional laminectomy that totally removes laminae piece by piece with attached ligamentous structures had been the standard surgical technique for cervical myelopathy caused by multi-level spondylosis and OPLL. However, both patients and surgeons had suffered from unpredictable surgical results due to the inherent traumatic nature of the technique leading to various complications.[1,2]

In 1968, Kirita devised a sophisticated technique in which the laminae were thinned and divided at the midline using a high speed drill followed by their en-bloc resection to achieve total decompression of the compressed spinal cord.[3] This technique added much safety to conventional laminectomy and significantly reduced the rate of neurological complications, however, vulnerability of the unprotected spinal cord and the recurrence of myelopathy due to the development of postoperative kyphosis or due to the formation of laminectomy membrane remained as unsolved problems.[4]

To address such problems, Hattori and his coworkers devised an expansive Z-plasty of the laminae in 1973, in which the laminae were preserved and reconstructed (Fig. 1).[5,6] However, this technique did not gain widespread acceptance because of its complicated technical aspects.

Hirabayashi modified Kirita's method and decompressed the spinal cord by making bilateral bony gutters by a high speed drill at the junction of laminae and facet joints followed by en bloc resection of the laminae.[7] The idea of open-door laminoplasty evolved when he noticed the presence of dural pulsation, a sign of decompression of the dural tube, at the lift of one side of the laminae just before their complete removal.[8] Instead of laminectomy, he performed the first case of this procedure in 1977 and named the technique ELAP. In 1981, he presented his first series of patients treated by ELAP with encouraging results in the English literature for the first time.[9] Since then, more than 500 patients underwent this procedure in our University Hospital and affiliated hospitals with satisfactory results.

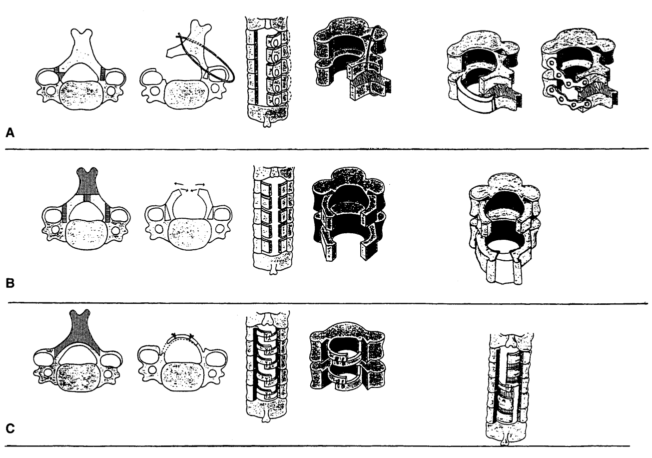

Fig. 1 Schematic drawing of a variety of laminoplasties, including A) open door, B) midsagittal splitting and C) Z-plasty. (taken from reference 7, with permission obtained from Lippincott Williams & Wilkins, Baltimore, MD, USA)

Rationale

Anterior decompression and fusion used to be the gold standard technique for the treatment for cervical myelopathy because it was considered logical to remove anterior pathological structures such as protruded discs, osteophytes and ossified ligaments, from an anterior approach. However, anterior fusions were not without complications, especially when a lesion involves multiple levels.[10] Long-term results of anterior fusions revealed that the recurrence of myelopathy was not uncommon, especially in patients with spinal stenosis.[11]

Unlike anterior decompression, anterior pathological structures cannot be directly removed by ELAP. However, it has a total decompression effect induced by the dorsal shift of the spinal cord, in addition to the local decompression effect by the displacement of the laminae, provided the patient's cervical alignment is maintained in lordosis (Fig. 2).[12]

The posterior structures including the lamina, supra- and interspinous ligaments are preserved to reconstruct the spinal canal and the cervical muscles are reattached to maintain cervical alignment, thereby restoring cervical stability.[13] Herkowitz concluded from his biomechanical study that the stability of the cervical spine after ELAP was not significantly different from that of the intact spine[14] and several other studies have proven that the decompression effect of ELAP is not different from that of laminectomy and anterior decompression followed by fusion.[15–17] The incidence of instability and degenerative changes in the adjacent levels, which may lead to a recurrent myelopathy, was significantly lower after ELAP than after anterior decompression and fusion.[7] Kyphotic deformity or instability after ELAP that required salvage anterior correction and fusion has never been experienced in our clinic.[7,18]

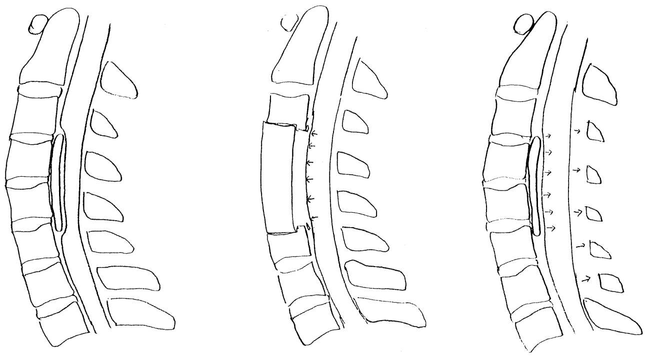

Fig. 2 Difference in the decompression mechanism between anterior decompression followed by fusion and expansive laminoplasty. A) The spinal cord is compressed by an anterior pathologic structure, in this case, by an ossified ligament. B) In anterior decompression, the ossified mass is directly removed. C) In posterior decompression, the spinal cord shifts posteriorly and is decompressed even though the ossified mass remains.

Indication

Hirabayashi considers ELAP as the treatment of choice for almost all patients with spinal canal stenosis whose anteroposterior diameter of the spinal canal is less than 13 mm even if they have single level disease including disc herniation, spondylosis or segmental OPLL.[7,19] For those without spinal canal stenosis, if the patient has a multilevel lesion, which extends beyond two segmental levels, ELAP is preferred over anterior fusion. Indication of anterior cervical fusion for cervical myelopathy has, therefore, been limited to patients with a single level lesion who have no spinal canal stenosis.[11] When a patient has severe established kyphosis associated with spinal stenosis, a two-staged surgery, which consists of first-stage ELAP followed by second-stage corrective anterior fusion, is planned. However, the secondary anterior fusion becomes unnecessary in most cases, because satisfactory improvement of myelopathy could be obtained after the first-stage ELAP.

Procedures and postoperative care

The patient is placed in a prone position on a surgical table with the head securely fixed with a Mayfield fixator firmly attached to the surgical table, and the table is tilted cranially upward at an angle of approximately 30 degrees. Tips of the spinous processes are exposed through a midline incision, then the bilateral paracervical muscles are stripped off from the laminae usually between C3 and C7 by cautery or a periosteal elevator. Once the paracervical muscles are detached from the laminae, the open side gutter is made at the junctions of the laminae and facet joints by a high speed drill with a cutting bur. The ventral cortex is either resected with a thin bladed Kerrison rongeur or perforated with a diamond bur. The ligamentum flavum at the upper and lower ends of the laminar door, usually at C2/3 and C7/T1 are resected with a thin bladed Kerrison rongeur. Then the bony gutter in the hinge side is made with the cutting bur slightly more lateral than the one in the open side. The stability of the hinge is checked frequently by applying a gentle bending force to the spinous processes to prevent hinge breakage by overdrilling. When all spinous processes and laminae become slightly mobile yet retaining spring-like resistance, the laminar door is ready to be opened. Pieces of suture are placed through the facet joint capsule and surrounding soft tissues at each level in the hinge side and are passed through interspinous ligaments around the base of the corresponding spinous process. Just prior to opening the laminar door, the patient's neck position is converted from a flexed to a neutral position. The tip of the blade of a large Kerrison rongeur is placed under the excised margin of one lamina and its edge is lifted slightly. The spinous process is held in the expanded position by fingers of an assistant. Then the next lamina is lifted in the same manner until all laminae are opened to the same extent. Repeat this procedure slowly and open the laminar door gradually. Release adhesions between the laminae and the dura with the spatula every now and then. Do not try to open one lamina extensively at one time or the hinge will break. Usually, dural pulsation can be observed in the middle of the opening procedure even before complete expansion. These maneuvers should be continued until the laminae of the open side become almost horizontal. To maintain the expanded position and to prevent the reclosure, threads previously placed at the base of the spinous processes are securely tied. A drainage tube is placed in the epidural space. The bilateral neck muscles are approximated to minimize the dead space and the nuchal ligament is tightly closed with nonabsorbable sutures. (Fig. 3)[7,8,13,20]

Postoperatively, the patient is ambulated at the 3rd postoperative day with a soft collar, which is worn for an average of a week. After its removal, the patient is encouraged to start gentle ROM exercise of the neck. Stitches are removed at 10 days postoperatively. The patients usually return to their work after 3 to 4 weeks. Rigorous activities including sports are permitted after 3 months postoperatively.

Refinement in surgical techniques

Since the advent of ELAP, Hirabayashi kept revising the technique.[7,13,21] These revisions include retention sutures placed around the base of the spinous processes to prevent laminar reclosure that had led to recurrent

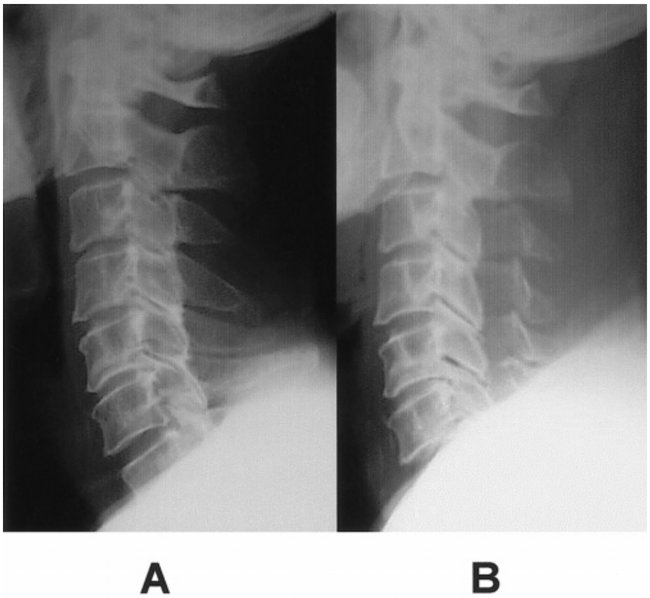

Fig. 3 Radiograph and CT after expansive open-door laminoplasty.

myelopathy requiring salvage laminectomy in one early case.[22]

Also in some early cases, breakage of the hinge was experienced while excising the ventral cortex of the open side with a Kerrison rongeur, because Hirabayashi initially made the gutters in both sides with a cutting bur followed by the resection of the ventral cortex in the open side. He therefore changed the sequence of the procedures, and made the hinge side gutter after completion of all other procedures, including the resection of the ventral cortex in the open side and flavectomy at the cephalad and caudal ends of the laminar door.[13,21]

To maintain and confirm cervical lordosis, which is important for the decompression mechanism of ELAP, Hirabayashi also added a number of improvements. He excluded the expansion of the C2 lamina whenever possible to preserved its spinous process where the semispinalis muscles attach.[7,13,21] He also tried to preserve the supraspinous and interspinous ligaments as much as possible. In some cases, these ligaments at the caudal end of the laminar door become tight and exert strong resistance, making sufficient expansion difficult. In such cases, the spinous process just below the caudal end of the expansion, usually that of T1, is exposed, and an osteotomy is carried out with a high-speed drill at its base and the process is bent toward the hinge side to relieve the tension of these ligaments.[7,21] The conversion of the patient's neck position from a flexed to a neutral position just before the laminar opening is another tip added by Hirabayashi. This not only allows the surgeon to confirm the lordotic alignment intraoperatively but also enables him or her to tie the stay sutures and reconstruct the muscular layers in the neutral position.

Clinical results

The long-term surgical results of 80 patients who underwent ELAP for myelopathy due to cervical spondylosis and OPLL with minimum 10 years follow-up were satisfactory.[23,24] Their recovery rates calculated using pre and postoperative Japanese Orthopaedic Association (JOA) scores were 53.1% for spondylosis and 47.9% for OPLL after an average follow-up of 14 years. Overall, 60% of the patients were rated as either excellent or good for cervical spondylotic myelopathy (CSM) and 55.0% for OPLL patients.

The preoperative duration of myelopathy, the age of the patient at the time of surgery, predisposition to trauma and the severity of spinal canal stenosis were the factors that significantly affected the clinical results. Patients over 65 years of age, those having myelopathy lasting over 2 years, those with an onset of the symptoms after trauma and those with severe spinal canal stenosis and kyphosis had significantly poor surgical results.[18,21]

Late gradual neurological deterioration, mainly in lower extremity motor function, developed in seven CSM and 16 OPLL patients whose average age at the final follow-up were 70 and 77 years respectively. Probable causes of the deterioration included comorbidities such as cerebrovascular, heart and degenerative lumbar diseases as well as progression of OPLL. However, such motor dysfunction may partly be due to normal aging processes.[23,24]

Sufficient decompression was verified in postoperative MR images in both CSM and OPLL patients although asymptomatic, degenerative changes at the cranial and caudal ends of laminar expansion were found in some patients and need further observation.

The percentage of patients with lordosis decreased from 70% preoperatively to 50% at the final follow-up and patients with non-lordotic alignment increased accordingly. Severe kyphotic deformity, however, did not develop in any patient. Even though there were no significant differences in the final recovery rates among patients with different alignments in both CSM and OPLL groups, those with kyphosis in the OPLL patients had much lower average recovery rate (9%) compared to those with lordosis (52%) and straight (38%).

Postoperative ROM on extension radiographs between C2 and C7 decreased significantly, while that between Occiput and C2 increased slightly making an overall decrease of approximately 35%.

Motor weakness in C5 or C6 segments was the most notorious complication, whose incidence was reported to be between 5 and 10%, although most of them recovered completely within 2 years postoperatively.[25] Approximately one third of patients complained of axial symptoms postoperatively such as shoulder and neck stiffness and pain. However, less than 10% were taking daily anti-inflammatory drugs due to such symptoms. Also, approximately one third of patients had complaints due to restricted ROM, mainly difficulty in turning back their heads and looking down at their toe tips, but most of them had minor disturbances in their ADL.[23,24]

A decrease in ROM due to fusion at the hinge side may stabilize the spine maintaining favorable long-term results, while at the same time may become a source of axial complaints. However, such drawbacks were, in some degree, compensated by upper cervical spine motion resulting in less ADL disturbances.[23,24]

Present status and future perspective of ELAP

Inspired by Hirabayashi's concept of ELAP and its favorable surgical results, various modifications have been developed in expansive laminoplasty, mostly in Japan, such as midsagittal splitting laminoplasties.[26] The open-door technique itself also has undergone a variety of modifications and additions including the use of bone grafts, spacers and plates trying to address problems of reclosure or postoperative malalignment.[27,28]

However, this fundamental yet innovative technique forms the basis for all other procedures and still remains to be the most viable options for the surgical treatment of compressive myelopathy. When compared with other modified laminoplasties, ELAP is the simplest and safest with less surgical impacts, i.e., shorter operating time, less bleeding and lower incidence of complications.[7,10,17,29]

With respect to the postoperative cervical stability, we feel that any spacers, grafts or instruments are unnecessary if we carefully follow the procedures mentioned above. ELAP seems to be a rational indication for the majority of cases of typical cervical stenotic myelopathy, whereas other expansive laminoplasties that use bone grafting, spacers, or plates may be indicated for those with a high degree of instability such as cerebral palsy.[7]

There still remain several problems to be solved in ELAP. The etiology of segmental motor paralysis is yet to be elucidated and no one has established effective preventive measures. Even though preservation of preoperative alignment has been possible to a certain degree, nobody has succeeded in correcting the preoperatively established kyphosis into physiological lordosis to date. So far, there is no effective way to regenerate the spinal cord function, once it is damaged irreversibly. We therefore recommend to perform ELAP as early as possible and ELAP is an ideal procedure which is considered to be reliable because it has the same decompression effect as laminectomy and is considered much safer and easier than anterior fusion for the severely deteriorated spinal cord. Such safety and reliability are the keys to make early operation possible, thereby achieving better clinical results.[7]

Percutaneous Nucleotomy

Lumbar disc herniation due to disc degeneration is one of the most common lesions affecting the back in all industrialized countries. The treatment for lumbar disc herniation had long been divided into two widely divergent modalities, conservative and surgical. At those times, if the patient failed conservative treatments, open surgery was the only remaining option available. However, results of surgeries were not always satisfying. Moreover, some patients were not available for surgery because of their poor general conditions and some refused surgery even though they were good candidates. In an attempt to avoid prolonged suffering from unsuccessful conservative treatment and to minimize the chance of morbidity often associated with open surgery, many surgeons sought alternative ways of decompressing a pathological disc. In 1964, Smith introduced chemonucleolysis, a dissolution of the nucleus pulposus using a proteolytic enzyme, chymopapain,[30] which subsequently gained wide popularity with acceptable results. However, the use of chemonucleolysis has declined dramatically in recent years because of a variety of complications, particularly those involving anaphylaxis and neurological loss which are rare but can be catastrophic.

Hijikata, who had actively participated in basic and clinical studies concerning the intervertebral disc degeneration, had much interest in novel treatment possibilities such as chemonucleolysis. He also was attracted by a paper published by Hult which suggested the possibility of partial discectomy and decompression of the intradiscal pressure through an anterolateral annular window that could bring relief from sciatica.[31] As a clinician, Hijikata had extensive experience in lumbar discography with hundreds of cases and through this experience, he noticed that in some patients, their symptoms were dramatically relieved on the day following discography.[32] Through these studies and experiences, the idea evolved that decompression of intradiscal pressure could be achieved percutaneously thereby relieving the symptoms of patients with a disc herniation without invasive surgery. After a great deal of anatomic research and refinement of appropriate instruments, the first percutaneous procedure was performed on March 6, 1975, in a 16-year-old boy with an excellent result.[33]

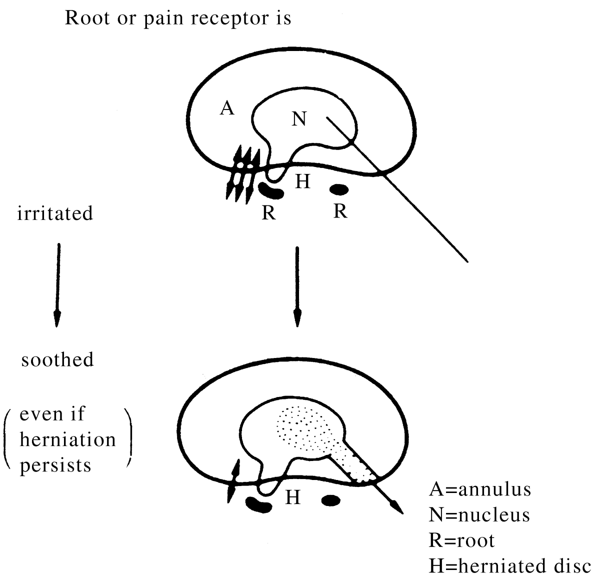

Fig. 4 Mechanism of pain relief in percutaneous nucleotomy. (taken from reference 32 with permission obtained from Lippincott Williams & Wilkins, Baltimore, MD, USA)

More than 25 years have passed since the first case of this new concept treatment, which he initially termed "percutaneous nuclectomy". This technique, now known as PN, has gained widespread acceptance as another alternative minimally invasive option for lumbar disc herniation.[32,34]

Rationale

Posterolateral disc puncture is followed by the sequential insertion of the guide pipes and the cannula. The annulus is perforated by a special cutter and a variety of punch forceps are inserted through the cannula, thus, fenestration of the annulus, partial removal of nuclear substance could be achieved percutaneously.[32] The restrictions imposed by the surgical approach and the instrumentation make it impossible to extract the herniated mass itself. However, intradiscal pressure is reduced considerably and relief from irritation of the nerve root or the pain receptors around the disc could be obtained (Fig. 4).[32]

In this procedure, the disc material mainly composed of the nucleus pulposus is extracted, which ultimately leads to decompression of intradiscal pressure. However, fenestration of the annulus may also play a significant role in the decompression mechanism. Many investigators therefore used a term percutaneous discectomy rather than nucleotomy, and Hijikata thinks that both terms are interchangeable.[32]

PN can be done in a radiology department under local anesthesia, just as the conventional discography and together with chemonucleolysis, this procedure is classified as one of the intradiscal or intermediate treatments that are located on the spectrum of treatment for lumbar disc herniation somewhere between conservative and surgical treatments.

Indications

PN is indicated in patients with clinical symptoms and signs typical of lumbar disc herniation such as pain or numbness extending into one leg with or without low back pain, restricted straight leg raising, neurological impairment including reflex abnormality, sensory disturbance and motor weakness, all of which were confined to an appropriate segmental distribution. The presence of evidence of a herniated disc in radiographic examinations such as myelography, discography, CT and MRI are imperative. Contained discs including protrusions and subligamentous extrusions are the best indications. All patients should undergo at least six weeks of conservative treatments, which include bracing, physical therapy and epidural steroid injections before being considered candidates for PN. Patients whose complaints are reproducible at discography are especially good candidates for this procedure.

Contraindications are sequestrated herniation, associated spinal stenosis, compensation and litigation cases, and patients with psychosocial problems. To improve clinical results of PN, it is essential to clearly define clinical and radiographical criteria for patient selection. Many investigators have recommended criteria based on their own experience.[35–37] For the patient who has no improvement postoperatively, Hijikata recommends conventional disc surgery within two or three weeks in order to minimize the patient's disability.

Instruments and procedures

Surgical instruments for PN have been designed to achieve rapid extraction of the disc material safely and accurately. A standard set of instruments for the procedure consists of a discography needle with a pilot sheath, three guide pipes with a different diameter and length, a cannula, an annulus cutter, and a variety of punch forceps. (Fig. 5)[32,33]

The procedure can be conducted in either an operating room or a fluoroscopy room in the radiology department. A fine fluoroscopic image control is essential. The patient is placed in a lateral decubitus position with symptomatic side uppermost should there be the laterality in leg symptoms. Pillows or towel rolls are placed underneath the patient's waist to insure a convexity of the patient's lumbar column at the site of puncture.

After thorough sterilization and draping, an abundant amount of 0.5% Xylocaine is injected into the skin all the way down to the disc. The target disc is punc-

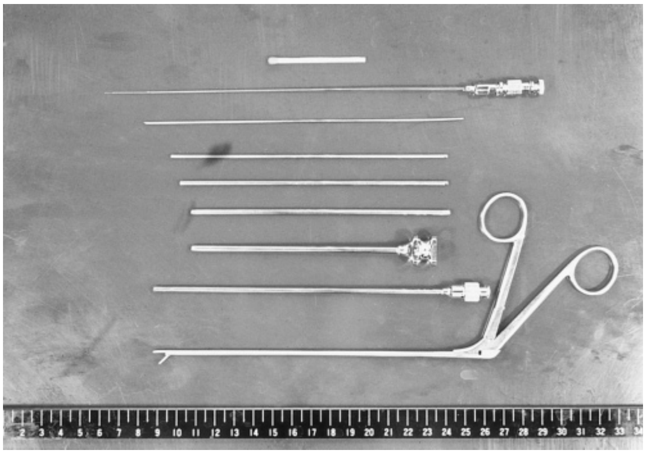

Fig. 5 A standard set of instruments for percutaneous nucleotomy. (taken from reference 32 with permission obtained from Lippincott Williams & Wilkins, Baltimore, MD, USA)

tured with a 19-gauge discography needle with a special pilot sheath through a posterolateral approach as in the conventional discography. In cases of the L5-S1 disc level, the entry point in the skin is near that of the L4–L5 disc with a needle inclined more caudally to avoid the iliac crest. Radiating pain is a sign of the irritation of the cranial nerve root and a small adjustment of the needle direction is necessary. Once the needle perforates the disc, the tip of the needle must be at or slightly posterior to the true center of the disc. A–P and lateral radiographs are taken to confirm the correct position of the needle tip.[32,34]

First, a mixture of radiopaque dye and methylene blue dye is injected into the disc. Reproduction of pain and radiographical findings are checked and are compared with those of the preoperative discography. After advancing the outer pilot sheath approximately 5 mm into the annulus, the discography needle is withdrawn, leaving the pilot sheath alone, which acts as a guide for the later procedures. A 5 mm skin incision is made at the entry point. Three progressively larger dilating pipes are placed over the initial guide pipe and one over the other. Finally, the cannula, the outside diameter of which is 4 mm, is advanced over the guide pipes to the disc margin. During these procedures, the patient's pain response should be monitored carefully to avoid nerve and vascular injuries. While the cannula is pushed firmly against the disc, the pilot sheath and the pipes are removed and the annulus cutter, which is saw-toothed, is inserted into the cannula and the annulus is perforated. Fluoroscopic control is used in order to avoid penetration of the endplates. The punch forceps are then inserted and disc material is removed. The patient complains of no pain as long as the forceps stay within the nucleus. If the extracted materials are not stained with the blue dye or the patient complains of pain, the forceps may be in the annulus and the danger of injuring the peripheral tissues becomes high. The direction of the cannula is changed carefully to remove as much nucleus as possible. At least 1 g, preferably 3 g of disc material should be extracted. Insert the annulus cutter into the disc once in a while so that a suction could be applied with a 30–50 mm syringe that is connected to the lurlock connector at the caudal end of the cutter. Extraction is finished when no further disc removal can be achieved. The cannula is then withdrawn quickly and surgical adhesive tape is used to close the skin. The entire procedure usually takes approximately 40 to 60 minutes. (Fig. 6)

Fig. 6 Extraction of disc materials with a punch forceps through the cannula.

The patient can be ambulated soon after the procedure. Hijikata recommends a relative rest period of three days after the procedure so as to monitor the patient's general and neurological status frequently within this period.[32]

Clinical results

Hijikata reported his experience in 136 patients with an average success rate of 72% in 1989. Among 28% unsuccessful cases, 19% were treated by subsequent conventional open surgery, mainly standard discectomy.[32] Clinical evaluations in his studies were done according to the criteria based on the Modified Japanese Orthopedic Association's score for low-back pain. By these criteria, 'excellent' indicates that the patient is almost free of complaints and has no restrictions in his or her daily life. 'Good' indicates that the patient has some or occasional complaints but is improved considerably and almost free of symptoms in daily activities. 'Fair' indicates that the patient's complaints and restrictions still remain. 'Poor' indicates no improvement or worsening of symptoms with considerable restrictions in daily activities. The success rates reported by others are similar and in the range between 53% and 94% with an average of 75%.

L4–L5 discs were most commonly and easily treated with favorable results. In the cases of L5-S1 discs, even though the punctures with a guide wire were possible in most cases, it was more difficult to place the needle tip in an ideal position due to anatomical reasons and disc extraction tended to be insufficient, therefore making the procedures less effective. Patients with contained herniations (i.e., bulging, protrusion, and subligamentous extrusion) had better results than those with uncontained transligamentous extrusions. Patients who had less disc material removed, and older patients tended to have inferior results.

On postoperative radiographs, disc narrowing was not found in most cases since only 1–3 g of disc material was extracted and only 4% of the discs showed significant narrowing of the disc space. Meanwhile, postoperative discograms in two cases showed that the opening made into the annulus was still patent even after nine months. In one case with an unsatisfactory result, postoperative discography revealed that too much of the anterior part of the disc had been removed. This patient underwent another PN, in which additional material was successfully removed from the posterior portion of the disc, ultimately providing a favorable result. Postoperative discograms often revealed the progression of disc degeneration after the procedure. MRI is effective in demonstrating the diminished size of the herniated mass and the site of disc removal as well as progression of disc degeneration. In his 25 years of experience, Hijikata had two infections and one minor vascular injury only. However, there have been reports on major vascular injury that required the open repair. Hijikata also experienced aggravation of leg pain immediately after the procedure in two patients. Emergency MRI revealed an increase in the size of the herniated mass in both cases. He assumed that the insertion and the manipulation of the punch forceps might have caused the increase in the intradiscal pressure and pushed out the disc fragment further into the spinal canal. In such case, he recommends emergency MRI followed by a surgical intervention to immediately salvage the patients' suffering.[34]

Present status and future perspective of PN

After 1983, many papers on PN have been published with satisfactory results, which had proven that Hijikata's initial idea of percutaneous disc decompression that could lead to the relief of sciatica and back pain is feasible.[36,38–45]

Over the years, PN has undergone a wide variety of technical modifications. Suezawa, also an alumnus of Keio, took the instruments and technique from Japan to Zurich, Switzerland, and together with Schreiber, developed and improved a technique and instruments with the combined use of intradiscal optical visualization using discoscopy.[43,45] Kambin and colleagues revised the technique and refined the instruments to fit the size of Western patients and published excellent clinical results of their PN.[38] Monteiro developed his own instruments and has reported over 400 cases with various kinds of back problems.[40] Onik, *et al.* have developed a new aspiration probe and a new technique of automatic percutaneous discectomy. One of the major advantages of Onik's method is that it uses smaller and thinner cannulas, the diameter of which is only 2.8 mm.[41,46]

The development of this initial PN procedure has opened the door to many other possible uses of the technique. Percutaneous cervical discectomy has been performed throughout the world, mostly using a nucleotome.[47] Techniques to achieve spondylodesis or arthorodesis through percutaneous approaches have been developed.[48] Introduction of laser vaporization of the nucleus pulposus was first reported by a Japanese spine surgeon and now has become one of the most preferred alternative treatments for disc herniation.[49] Intradiscal thermal modulation of the disc for internal derangement of the disc is now widely used in the U.S. as a popular alternative treatment for low back pain.[50]

One of the most significant contributions of Hijikata is the development of the sophisticated technique to access the disc safely and effectively using a guide wire and soft tissue dilating devices. The concept of this technique is now commonly used in various minimally invasive procedures including laparoscopic surgeries and microendoscopic discectomy.[51]

The prevalence of these minimally invasive treatment alternatives has led to the establishment of a new form of treatment called "intermediate therapy", representing these alternative therapies that are located between conservative and surgical treatments in the spectrum of treatment for lumbar disc herniation. However, because of their inherent indirect nature, clinical outcomes of these procedures are in the 70% range.[32,37–39,41,43,44]

The surgeons who use these alternative treatments should, therefore, always be reminded that PN is not a part of conservative treatments that can be prescribed easily nor an absolute replacement for conventional surgeries. It is a treatment in its own right and all conservative, intermediate and surgical treatments have their own advantages and disadvantages. However, there is concern about the risks that may be encountered by the rapid use of this procedure by less-experienced persons without the proper indications for its use.[34] When indicating PN for patients with disc problems, there are two fundamental ideas that could be chosen. One is to select patients carefully through strict criteria in order to obtain a higher success rate.[36,37] The other is to apply PN aggressively, before any major surgery is contemplated, if the patient falls into any category that is amenable to PN.[34] Hijikata believes that both are practical as long as the selection is made on the basis of patients' benefits and the best choice may lie somewhere between the two ideas. However, he has kept warning that the abuse of the technique based on the commercialism on the surgeons' side or excessive enthusiasm for new treatments on the patients' side should strictly be prohibited. Even though PN is much less invasive to surrounding soft tissues, the damage to the disc itself is comparable or, in some cases, greater than open surgery.[34] Many patients with disc herniations or back pain without sciatica caused by disc degeneration, can be satisfactorily treated by PN. Both surgeons and patients would benefit from having PN as a choice among a variety of treatment modalities for lumbar disc herniation.

It is our great pleasure to know that our alumni have established innovative treatment modalities that have changed the stream of managements for the most common spinal disorders and have greatly contributed to the relief from pains and disabilities of many patients. Both of them were devoted to look for a better patient care, had the ability to get inspirations from their daily clinical experiences that most of us would overlook and had the courage and strong will to put their ideas into reality. It is our obligation to keep revising the original techniques to improve the outcome yet to preserve the fundamental rationale that reside in these original ideas and concepts and pass them on to the next generation.

References

1. Bohlman HH: Cervical spondylosis with moderate to severe myelopathy. Spine 1977; 2: 151–162
2. Mayfield FH: Complications of laminectomy. Clin Neurosurg 1976; 23: 435–439
3. Kirita Y: Posterior decompression for cervical spondylosis and OPLL. Shujutsu (Surgery) 1976; 30: 287–302 (in Japanese)
4. Cattell HS, Clark GL Jr: Cervical kyphosis and instability following multiple laminectomies in children. J Bone Joint Surg Am 1967; 49: 713–720
5. Kawai S, Sunago K, Doi K, Saika M, Taguchi T: Cervical laminoplasty (Hattori's method). Procedure and follow-up results. Spine 1988; 13: 1245–1250
6. Oyama M, Hattori S, Moriwaki N, Nitta S: A new method of cervical laminectomy. Chubu Nippon Seikeisaigaigeka Gakkai Zasshi (Central Jpn J Orthop Traumatol) 1973; 16: 792–794 (in Japanese)
7. Hirabayashi K, Toyama Y, Chiba K: Expansive laminoplasty for myelopathy in ossification of the longitudinal ligament. Clin Orthop 1999; 359: 35–48
8. Hirabayashi K: Expansive open-door laminoplasty for cervical spondylotic myelopathy. Shujutsu (Operation) 1978; 32: 1159–1163 (in Japanese)
9. Hirabayashi K, Miyakawa J, Satomi K, Maruyama T, Wakano K: Operative results and postoperative progression of ossification among patients with ossification of cervical posterior longitudinal ligament. Spine 1981; 6: 354–364
10. Yonenobu K, Fuji T, Ono K, Okada K, Yamamoto T, Harada N: Choice of surgical treatment for multisegmental cervical spondylotic myelopathy. Spine 1985; 10: 710–716
11. Toyama Y, Hirabayashi H, Kamata M, Fujimura Y, Satomi K, Hirabayashi K: Long-term clinical results of anterior interbody fusion for cervical spondylotic myelopathy. Higashi Nippon Seikeisaigaigeka Gakkai Zasshi (J East Jpn Orthop Traumatol) 1997; 9: 487–492 (in Japanese)
12. Fujimura Y, Nishi Y, Nakamura M: Dorsal shift and expansion of the spinal cord after expansive open-door laminoplasty. J Spinal Disord 1997; 10: 282–287
13. Hirabayashi K: Expansive open-door laminoplasty. In: Sherk HH, Dunn EJ, Eismont FJ, eds, The Cervical Spine: An Atlas of Surgical Procedures, Philadelphia, Lippincott, 1994: 233–250
14. Herkowitz HN: A comparison of anterior cervical fusion, cervical laminectomy, and cervical laminoplasty for the surgical management of multiple level spondylotic radiculopathy. Spine 1988; 13: 774–780
15. Herkowitz HN: Cervical laminaplasty: its role in the treatment of cervical radiculopathy. J Spinal Disord 1988; 1: 179–188
16. Norwinski GP, Visarius H, Nolte LP, Herkowitz HN: A biomechanical comparison of cervical laminaplasty and cervical laminectomy with progressive facetectomy. Spine 1993; 18: 1995–2004
17. Yonenobu K, Hosono N, Iwasaki M, Asano M, Ono K: Laminoplasty versus subtotal corpectomy. A comparative study of results in multisegmental cervical spondylotic myelopathy. Spine 1992; 17: 1281–1284
18. Satomi K, Nishi Y, Kohno T, Hirabayashi K: Long-term follow-up studies of open-door expansive laminoplasty for cervical stenotic myelopathy. Spine 1994; 19: 507–510
19. Hirabayashi K, Toyama Y: Choice of surgical procedure for cervical ossification of the posterior longitudinal ligaments. In: Yonenobu K, Sakou T, Ono K, eds, OPLL: Ossification of the Posterior Longitudinal Ligament, Tokyo, Springer-Verlag, 1997; 135–142
20. Hirabayashi K, Satomi K: Operative procedure and results of expansive open-door laminoplasty. Spine 1988; 13: 870–876
21. Hirabayashi K, Satomi K, Toyama Y: Surgical management of OPLL: anterior versus posterior approach part II. In: CSRS, eds, The Cervical Spine, Philadelphia, Lippincott-Raven, 1998; 876–887
22. Hirabayashi K, Watanabe K, Wakano K, Suzuki N, Satomi K, Ishii Y: Expansive open-door laminoplasty for cervical spinal stenotic myelopathy. Spine 1983; 8: 693–699
23. Maruiwa H, Chiba K, Watanabe M, Matsumoto M, Fujimura Y, Hirabayashi K, Toyama Y: Long-term results of expansive open-door laminoplasty for cervical spondylotic myelopathy. Rinsho Seikeigeka (Clin Orthop Surg) 2000; 35: 411–416 (in Japanese)
24. Maruiwa H, Kamata M, Watanabe M, Matsumoto M, Chiba K, Fujimura Y, Hirabayashi K, Toyama Y: Long-term results of expansive open-door laminoplasty for ossification of the longitudinal ligament. Nippn Seikeigeka Gakkai Zasshi (J Jpn Orthop Assoc) 2000; 74: S690 (in Japanese)
25. Chiba K, Watanabe M, Maruiwa H, Matsumoto M, Fujimura Y, Toyama Y: Segmental motor paralysis after expansive open-

door laminoplasty. Rinsho Seikeigeka (Clin Orthop Surg) 2000; 35: 607–612 (in Japanese)
26. Kurokawa T, Tsuyama N, Tanaka H: Enlargement of spinal canal by the sagittal splitting of the spinous process. Bessatsu Seikeigeka (Orthop Surg) 1982; 2: 234–240 (in Japanese)
27. Itoh T, Tsuji H: Technical improvements and results of laminoplasty for compressive myelopathy in the cervical spine. Spine 1985; 10: 729–736
28. Matsuzaki H, Hoshino M, Kiuchi T, Toriyama S: Dome-like expansive laminoplasty for the second cervical vertebra. Spine 1989; 14: 1198–1203
29. Iwasaki M, Ebara S, Miyamoto S, Wada E, Yonenobu K: Expansive laminoplasty for cervical radiculomyelopathy due to soft disc herniation. Spine 1996; 21: 32–38
30. Smith L: Enzyme dissolution of the nucleus pulposus in humans. JAMA 1964; 187: 137–140
31. Hult L: Retroperitoneal disc fenestration in low-back pain and sciatica. Acta Orthop Scandinav 1951; 20: 342–348
32. Hijikata S: Percutaneous nucleotomy. A new concept technique and 12 years' experience. Clin Orthop 1989; 238: 9–23
33. Hijikata S, Yamagishi M, Nakayama T, Oohashi K: Percutaneous nuclectomy: A new treatment method for lumbar disc herniation. Toden Iho (J Tokyo Den-ryoku Hosp) 1975; 5: 39–44 (in Japanese)
34. Hijikata S: Percutaneous Nucleotomy. Nippon Sekituigeka Gakkai Zasshi (J Jpn Spine Res Soc) 1999; 10: 308–317 (in Japanese)
35. Castagnera L, Grenier N, Lavignolle B, Greselle JF, Senegas J, Caille JM: Study of correlation between intradiscal pressure and magnetic resonance imaging data in evaluation of disc degeneration. Therapeutic issue with percutaneous nucleotomy. Spine 1991; 16: 348–352
36. Mochida J, Arima T: Percutaneous nucleotomy in lumbar disc herniation. A prospective study. Spine 1993; 18: 2063–2068
37. Mochida J, Toh E, Nishimura K, Nomura T, Arima T: Percutaneous nucleotomy in lumbar disc herniation. Patient selection and role in various treatments. Spine 1993; 18: 2212–2217
38. Kambin P, Schaffer JL: Percutaneous lumbar discectomy. Clin Orthop 1989; 238: 24–34
39. Mayer HM, Brock M: Percutaneous endoscopic discectomy: surgical technique and preliminary results compared to microsurgical discectomy. J Neurosurg 1993; 78: 216–225
40. Monteiro A, Lefevre R, Pieters G, Wilmet E: Lateral decompression of a pathological disc in the treatment of lumbar pain and sciatica. Clini Orthop 1989; 238: 56–63
41. Onik G, Helms CA, Grinsberg L, Hoaglund FT, Morris J: Percutaneous lumbar diskectomy using a new aspiration probe. Radiology 1985; 155: 251–252
42. Sakou T, Masuda A, Yone K, Nakagawa M: Percutaneous discectomy in athletes. Spine 1993; 18: 2218–2221
43. Schreiber A, Suezawa Y, Leu H: Does percutaneous nucleotomy with discoscopy replace conventional discectomy? Eight years of experience and results in treatment of herniated lumbar disc. Clin Orthop 1989; 238: 35–42
44. Shepperd JA, James SE, Leach AB: Percutaneous disc surgery. Clin Orthop 1989; 238: 43–49
45. Suezawa Y, Jacob HA: Percutaneous nucleotomy. An alternative to spinal surgery. Arch Orthop Trauma Surg 1986; 105: 287–295
46. Onik G, Helms CA, Ginsberg L, Hoaglund FT, Morris J: Percutaneous lumbar diskectomy using a new aspiration probe. Am J Roentgenol 1985; 144: 1137–1140
47. Bonaldi G, Minonzio G, Belloni G, Dorizzi A, Fachinetti P, Marra A, Goddi A: Percutaneous cervical diskectomy: preliminary experience. Neuroradiology 1994; 36: 483–486
48. Leu HF, Hauser RK, Schreiber A: Lumbar percutaneous endoscopic interbody fusion. Clin Orthop 1997; 337: 58–63
49. Yonezawa T, Onomura T, Kosaka R, Miyaji Y, Tanaka S, Watanabe H, Abe Y, Imachi K, Atumi K, Chinzei T, *et al.*: The system and procedures of percutaneous intradiscal laser nucleotomy. Spine 1990; 15: 1175–1185
50. Saal JA, Saal JS: Intradiscal electrothermal treatment for chronic discogenic low back pain: a prospective outcome study with minimum 1-year follow-up. Spine 2000; 25: 2622–2627
51. Brayda-Bruno M, Cinnella P: Posterior endoscopic discectomy (and other procedures). Eur Spine J 2000; 9 (Suppl 1): S24–S29