Percutaneous Laser Disc Decompression for the Treatment of Lumbar Disc Herniation: A Review

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Background: Discontinuation of the marketing of chymodactin has reawakened interest in other percutaneous techniques for treating lumbar disc herniation. Developed in the 1980s, the concept of laser disc decompression is based on the percutaneous introduction of an optical fiber into the intervertebral disc and administering laser energy. The procedure allows for the vaporization of a small amount of the nucleus pulposus and hence a reduction in the intradisc pressure and relief of radicular pain.

Objectives: To review of the literature and summarize the technical modalities, mechanism, indications for, and results of percutaneous laser disc decompression for treating lumbar disc herniation.

Methods: We identified studies of percutaneous laser disc decompression published between January 1980 and June 2006 in the MEDLINE, EMBASE, and Cochrane Library databases. The search terms used were percutaneous laser disc decompression, laser, and spine or lumbar, disc or disk. The articles underwent a stepwise selection process on the basis of their title, abstract, and full text.

Results: Experimental and clinical studies have investigated the modality of percutaneous laser disc decompression, but no consensus exists on the type of laser to use, the wavelength, duration of application, or appropriate energy applied. Studies have evaluated the impact of different techniques on the amount of disc removed, intradisc pressure, and damage to neighboring tissue. Several open studies have been published, but their methodology and conclusions are questionable, and no controlled study has been performed.

Conclusions: Although the concept of laser disc nucleotomy is appealing, this treatment cannot be considered validated for disc herniation-associated radiculopathy resistant to medical treatment.
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Keywords: *review, nucleotomy, laser, disc herniation, wavelength*

Percutaneous techniques provide an alternative to surgical treatment of herniation of lumbar discs and can be divided into dissolution mechanisms (chymodactin), ablation (nucleotomy or surgery), and vaporization (laser) of the nucleus pulposus (NP). Of these, nucleolysis with chymodactin has been the most thoroughly studied, with extensive evidence of its effectiveness and lack of untoward effects (1). Used as a proteolytic enzyme for the dissolution of disc herniation, chymodactin causes hydrolysis of noncollagenous proteins providing the connections between chains of mucopolysaccharides, thus provoking depolymerization of the NP, a reduction in intradisc pressure, and the disappearance of radicular pain (2). The first animal experiments were performed in 1963 (3), and 4 of the 5 controlled studies published between 1976 and 1988 (4-8) showed good efficacy with chymodactin. Several open studies have confirmed the short- and long-term effectiveness of chymodactin (1). Chemonucleolysis with chymodactin was a satisfactory alternative to disc surgery until the end of the 1990s. However, chymodactin has not been available

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since 2001 because it was abandoned by the manufacturer in part because of its inordinately high cost.

Two other percutaneous techniques for treating herniation of lumbar discs were developed in the 1980s—manual nucleotomy (9) and an automated method (10). Use of manual nucleotomy has expanded rapidly in the surgical fraternity (11). The first results with automated nucleotomy involving an aspiration probe were published in 1987 (12), and these were followed by results of a larger series (13). A controlled study comparing automated nucleotomy with chymodactin-induced chemonucleolysis showed the superiority of the latter (14). Thus, manual and automated nucleotomy were abandoned because they were not sufficiently effective.

The lack of availability of these techniques in Europe gave rise to the use of percutaneous laser (Light Amplification by Stimulated Emission of Radiation) disc decompression (PLDD). This review of the literature describes the technical modalities, mechanism, indications for, and success of this technique in treating lumbar disc herniation.

METHODS

Search Strategy

We performed a literature search of the MEDLINE, EMBASE, and Cochrane Library databases for articles published from January 1980 to June 2006. Articles dealing with PLDD for the treatment of lumbar disc herniation were considered if they were written in English or French. Systematic reviews, meta-analyses, randomized controlled trials, nonrandomized controlled trials, and observational studies were included. In addition, we searched for abstracts of communications delivered at the annual meetings of the International Society for the Study of the Lumbar Spine, the North American Spine Society, the French Society for Rheumatology, European League Against Rheumatism, and American College of Rheumatology from 1995 to the present.

Article Selection

The following keywords were used to retrieve publications: percutaneous laser disc decompression, laser, and spine or lumbar, disc or disk. The articles retrieved underwent a stepwise selection process on the basis of their title, abstract, and full text, in that order. A score was assigned to each selected study depending on its design (ie, the likelihood of bias). The score was used to define the level of evidence from the study (Table 1).

RESULTS

The quality of information available about this procedure was poor. None of the articles offered high-quality evidence, particularly because of the current lack of controlled, blinded, or randomized trials; thus, the articles had a level of evidence of 3 or 4.

Table 1 Classification of Levels of Evidence in Published Articles According to Study Design

Level	Evidence Based on
1a	A meta-analysis of randomized controlled trials
1b	At least 1 randomized controlled trial
2a	At least 1 controlled trial without randomization
2b	At least 1 other type of quasi-experimental study
3	Nonexperimental descriptive studies
4	Expert opinion, clinical experience of respected authorities

History

Treatment of the first patient with herniation of a lumbar disc by use of laser decompression took place in 1986, and a report of the first 12 patients was published in 1987 (Letter to the Editor, *New England Journal of Medicine* (15)) (The author noted that an Ethics Committee would not have authorized the treatment in the United States because of insufficient in vitro or animal studies (16)). PLDD was approved by the US Food and Drug Administration (FDA) in 1991, and since the withdrawal of chymodactin from the market, more investigators have focused on this technique, despite the lack of consensus on the indications for treatment or evaluation of results. The number of patients subsequently treated by this method is surprising (more than 30,000 in 2001 (16)), as are the number of series published, despite the absence of a controlled study in 20 years and the debatable validation of the technique and its results. Among the reviews on the subject (17-19), 2 were cautious regarding effectiveness and safety and recommended a controlled study, still not performed to date (17,18). The initiator of the technique, Choy, reported on a series of 752 PLDD performed in 518 patients in 1988 (20), and in France, Gangi and coworkers, of Strasbourg, have had the most experience (21).

Rationale and Mechanisms of Action of PLDD

The concept of PLDD is based on the percutaneous introduction of an optical fiber into the intervertebral disc by means of a small-diameter needle and the administration of laser energy. This permits the vaporization of a small amount of NP in the central part of the disc, significant reduction in intradisc pressure, and the disappearance of disc-related pain (17-21).

Optimal Wavelength

Consensus is lacking on the type of laser used, the energy applied, or duration of application (17). Various types of lasers have been evaluated: those close to the infrared region (neodymium:ytrium-aluminum-garnet laser [Nd:YAG] (15,22,23); holmium:ytrium-aluminum-garnet laser [Ho:YAG] (24,25); diode laser) and lasers with visible green radiation (double-frequency Nd:YAG or potassium-titanyl-phosphate [KTP] laser) (26). Low absorption results in the vaporization of an insufficient amount of NP (17), but high energy can increase risk of tissue burning. However, increasing the length and frequency of pauses between energy application is possible. The destruction of the disc by laser is influenced by the absorption of the energy by water, and the optimal wavelength should be close to the absorption band of water (2000 nm) (17,25). The clinical consequences of the absorption properties are poorly understood and consensus is lacking on the ideal wavelength.

In 1 study, sections of NP were cut from human intervertebral discs following a single exposure to laser irradiation at various energies for each wavelength studied (193 nm Excimer, 488 and 514 nm Argon, 1064 nm Nd:YAG, 1318 nm Nd:YAG, 2150 nm Ho:YAG, 2940 nm Erbium:YAG, 10,600 nm CO_2) (27). Samples were weighed before and after treatment, the difference corresponding to the amount of NP extracted. Erbium:YAG at 2940 nm and CO_2 at 10,600 nm were the most effective in terms of amount of NP extracted/J of irradiation but were considered difficult to use for technical reasons. The authors of the study considered Nd:YAG laser at 1064 nm the best choice.

An 805-nm diode laser, the absorption of which was enhanced by injection of indocyanine green (ICG), was evaluated in dogs (28). ICG yielded an NP attenuation coefficient 100 times higher than that for non-ICG-treated NP; 1, 3, or 5 W energy applied after ICG reduced NP weight by 20, 45, and 65%, respectively. Without ICG, the power required was greater (15 W), leading to risk of damage to neighboring tissues. However, this procedure has not been used in humans.

Amount of Disc Removed

Experiments to evaluate the amount of disc tissue vaporized by laser have yielded varying results not easily reproducible. Choy and coworkers reported that administration of 1000 J with a 1064-nm Nd:YAG laser vaporized 98 mg of NP (22). One study, involving a high-power Ho:YAG laser, showed a linear increase in amount of NP removed according to the energy delivered, with no change above 20 W; the highest temperatures were noted after the application of 500 J (29). The amount of human NP removed by a 2100-nm Ho:YAG laser is reported to be 0.6 g dry weight (30). The effect of different wavelengths (1064, 1320, 1440, 2100 nm) on intervertebral discs has been evaluated in terms of the amount of NP removed (bovine NP) and the temperature reached (human vertebrae) (31). Variations in a single parameter (power, frequency, impulsion energy) had minimal effect, the determining factor being the total energy applied. The authors of this study concluded that Ho:YAG and Nd:YAG lasers were suitable for disc decompression. In comparison, the amount of disc tissue removed by automated nucleotomy is 2 to 7 g (32).

Reduction of Intradisc Pressure

Various studies have evaluated the influence of vaporization on disc pressure (33-36), which suggests that the intervertebral disc behaves like a hydraulic system in which a slight reduction in volume induced by the laser results in major variations in intradisc pressure. Yonezawa and coworkers reported a significant reduction in disc pressure induced by vertical load in rabbits following treatment with a 1064-nm Nd:YAG laser (23,33), and disc pressure was also significantly reduced after laser ablation of small amounts of NP (34). Choy and Altman reported a greater than 50% reduction following treatment with a 1320-nm Nd:YAG laser (35); a transducer introduced into the NP of human discs in a system maintaining them in a vertical position measured pressure constantly before and after charge, both before and after treatment. The control group underwent the same procedure but without activation of the laser. The initial pressure of 1175 ± 473 mm Hg increased to 2419 ± 589 mm Hg after charge and fell to 1075 ± 484 mm Hg after treatment, for a reduction of 1344 ± 601 mm Hg (56%). No reduction occurred in the control group.

The pressure/volume ratio of the NP, and the variations in pressure induced by a given change in volume of NP, has been studied in the intervertebral discs of fresh human cadavers (36). Pressure was recorded in parallel with progressive increase in volume by injection of saline solution, with and without the addition of vertical pressure. Intradisc pressure increased rapidly and progres-

Table 2 Indications for Laser Disc Decompression (21)
Inclusion criteria (patients must meet all 3)
1. Contained disc herniation demonstrated on magnetic resonance imaging or computed tomography
2. Neurological findings referring to a single nerve root
Leg pain of greater intensity than back pain
Positive straight-leg-raising test (Lasègue's sign)
Decreased sensation, motor response, and tendon reflex
3. No improvement after 6 weeks' conservative treatment
Exclusion criteria
• Hemorrhagic diathesis
• Spondylolisthesis
• Spinal stenosis
• Previous surgery at the indicated disc level
• Significant psychological disorder
• Significant narrowing of the disc space
• Possibility of monetary gain (eg, from a work accident)
• Pregnancy
• Cauda equina syndrome

Table 3 Percutaneous Laser Disc Decompression: Treatment Procedure According to Published Results

Author (y, reference)	Patient Characteristics			Disease
	No. PLDD/ Patients	Age (y)	Sex (Male)	
Choy (1987) (15)	*/12			Disc herniation
Choy (1992) (22)	377/333	23–81	192	Disc herniation
Ohnmeiss (1994) (55)	*/204	42.7 (20–82)	88	Disc herniation
Liebler (1995) (58)	148/117			Disc herniation
Casper (1995) (59)	*/223	46.3 (13–81)	113	Disc herniation
Choy (1995) (61)	389/322	17–89	189	Disc herniation
Chambers(1995) (62)	272/231	43	131	Disc herniation
Bosacco (1996) (63)	*/61	48 (28–68)	33	Disc herniation
Casper (1996) (60)	105/100	43.3 (18–75)	50	Disc herniation
Gangi (1996) (21)	*/119	12–71	67	Disc herniation
Nerubay (1997) (65)	50/50	34	38	Disc herniation
Choy (1998) (20)	752/518	17–92	317	Disc herniation
	Results: 350 patients	50.4	210	
Gevargez (2000) (66)	*/26	64.5 (31–82)		Disc herniation
Knight (2002) (67)	687/576	43 (18–80)		Painful disc protrusion or discogenic pain (discography)
Gangi (communication, 2002)	*/412			Disc herniation
Gronemeyer (2003) (71)	*/200	46 ± 12 (20–81)	90	Disc herniation
Tassi (2004) (68)	98/92	41 (21–79)	53	Disc herniation
Black (2004) (69)	59/32		23	Discogenic low back pain (discography)
McMillan (2004) (70)	*/32			Discogenic low back pain (discography) with sciatica in 30 patients

*Number of procedures not specified.

sively during injection, with and without additional vertical pressure, with a strong linear correlation between volume and pressure ($r = 0.96$).

Impact on Biochemical Factors

The impact of PLDD on chemical factors identified in the genesis of sciatica (37) has been studied in relation to rates of nerve conduction velocity and levels of prostaglandins E_2 (PGE_2) and phospholipase A_2 (PLA_2) before and after laser treatment in rabbits (38). Nerve conduction velocity rates were significantly increased in the laser-treated group as compared with nontreated animals, and PGE_2 and PLA_2 levels were reduced. However, the effect of decreased disc pressure on nerve function has not been substantiated in humans.

Impact of Laser on Intervertebral Discs and Neighboring Tissue

The application of laser energy may cause damage to the intervertebral disc and neighboring tissue (39,40). Magnetic resonance imaging (MRI) of rabbit muscle immediately after Nd:YAG laser treatment demonstrated 3 layers affected: a central area of low signal intensity corresponding to the vaporized cavity; a wider area of low signal intensity corresponding to necrosis due to coagulation; and a peripheral area of high signal intensity corresponding to interstitial edema (41). MRI following treatment with a Ho:YAG laser in cadaveric discs gave low intensity signals corresponding to areas of vaporization (42). Histology revealed carbonization of surface tissue and, immediately below it, necrosis and vacuolization-type abnormalities due to thermal coagulation, with correlation between intensity of the signal and histological abnormalities.

The size of the disc herniation and the intensity of the signal from the disc and the neighboring vertebral body (MRI) before and 24 hours after PLDD with a Ho:YAG laser were evaluated in 29 intervertebral discs (43). An increase in the intensity of the signal coming from the disc was noted, without any change in size of herniation, with no association between the initial size of the herniation, changes in the signal from the disc, or clinical outcome. Another study failed to demonstrate any difference between

Table 3 Continued

Duration of Symptoms (months)	Level Treated	Laser Used	
		Type	Multple Procedures/ No. of Patients
	L3-L4: 1, L4-L5: 8, L5-S1: 3	1060 nm Nd:YAG	*
>3	L2-L3: 2, L3-L4: 30, L4-L5: 226, L5-S1: 119	279: 1320 nm Nd:YAG 54: 1060 nm Nd:YAG	Yes/11
>2		532 nm KTP	*
>2	L2-L3: 5, L3-L4: 21, L4-L5: 76, L5-S1: 46	532 nm KTP	Yes/*
24.8 ± 47.9	L1-L2: 3; L2-L3: 4; L3-L4: 17; L4-L5: 115; L5-S1: 113	2150 nm Ho:YAG	Yes/26
	C4-C5: 2; C5-C6: 8; C6-C7: 4; L1-L2: 4; L2-L3: 11; L3-L4: 23; L4-L5: 195; L5-S1: 142	1060 nm Nd:YAG	Yes/*
	L4-L5: 148, L5-S1: 81	1060 nm Nd:YAG	Yes/46
	L4-L5, L5-S1	532 nm KTP	No
3.6 (1.5–360)	L2-L3: 1, L3-L4: 4, L4-L5: 49, L5-S1: 51	2150 nm Ho:YAG	Yes/5
	L3-L4: 4, L4-L5: 53, L5-S1: 62	1060 nm Nd:YAG	Yes/7
33 (4–120)	L4-L5: 50	Carbon dioxide	No
>3 >6 (305 patients)	699 lumbar (497 patients), 47 (27 patients) cervical, 6 thoracic	1060 nm Nd:YAG	Yes/75
>2	L3-L4, L4-L5, L5-S1	980 nm Cerelas-D diode	No
54 (8–234)		532 nm KTP	Yes/*
		1064 nm Nd:YAG	Yes/*
	L1-L2: 1, L2-L3: 1, L3-L4: 7, L4-L5: 105, L5-S1: 84	1064 nm Nd:YAG	*
	L2-L3: 3; L3-L4: 11; L4-L5: 46; L5-S1: 38	1064 nm Nd:YAG	Yes/2 levels in 6 patients
	T8-T9: 1; T12-L1: 1; L1-L2: 1; L2-L3: 4; L3-L4: 11; L4-L5: 20; L5-S1: 21		Yes/*
	L3-L4, L4-L5, L5-S1	1064 nm Nd:YAG	Yes/*

symptomatic and asymptomatic patients in prevalence of subchondral abnormalities seen on MRI, nor any difference in prevalence of low back pain in patients with or without MRI-detected subchondral abnormalities (44).

Animal Studies

Animal studies were mainly performed in the 1990s (ie, after the first human experiments). Histological study of changes induced by application of laser in rabbits showed the following: vaporization of the NP and the formation of a central cavity on day 1 and at 1 week; proliferation of cartilaginous cells and fibrous tissue at 3 and 4 weeks; and the almost complete replacement of the NP by fibrocartilaginous tissue at 8 weeks (23). In pigs killed 2 to 8 weeks following treatment with a 2100-nm Ho:YAG laser, discs were fibrous and rubbery as compared with normal gelatinous discs, and intrusions into the vertebral endplates were seen, without thermal lesions to the nerve structures (45). The use of a 2100-nm Ho:YAG laser did not increase the temperature in the posterior longitudinal ligament in pigs, and necrotic lesions sparing the nerve structures were seen at 1 week (46).

The use of an Nd:YAG laser in a degenerated pig disc model did not result in significant changes; the vaporized area was replaced progressively with fibrocartilaginous tissue, and the changes seen on MRI resolved after 60 days (47). The use of an Nd:YAG laser in another degenerated pig disc model resulted in a significant reduction in vascularization of the vertebral endplates (45).

Techniques and Practical Modalities

The use of the laser nucleotomy technique, fully described by Gangi and coworkers (21), varies according to author (18,21,22). The laser is usually guided by the use of fluoroscopy (48), which permits imaging of all planes, but not soft tissue, and exposes both the patient and the operator to a certain degree of irradiation. Computed tomography (CT) allows for guiding the position of the needle by visualizing the bony structures and soft tissue, but provides imaging on only 1 plane. Thus the combination of fluoroscopy and CT permits 3-dimensional visualization of anatomical structures (49,50).

Gangi and coworkers used a 1064-nm Nd:YAG laser with a 18-gauge needle and an optical fiber, 400 μm in

Table 4 Percutaneous Laser Disc Decompression: Success of Treatment

Author (y, reference)	Follow-Up (mo)	Success Assessment	Immediate Improvement
Choy (1987) (15)			9/12 patients
Choy (1992) (22)	26 (Max: 62)	McNab criteria	166 patients
Ohnmeiss (1994) (55)	13.2	No surgery, benefit recognized by the patient, return to work	
Liebler (1995) (58)	24 (23 patients) 12 (46 patients)	McNab criteria	"In many instances"
Casper (1995) (59)	12	Modified McNab criteria	
Choy (1995) (61)	62	McNab criteria	90% (successful patients)
Chambers (1995) (62)			
Bosacco (1996) (63)	31.75 (20–45)	Andrews and Lavyne scale	
Casper (1996) (60)	24	Modified McNab criteria	
Gangi (1996) (21)	13 (max: 35)	McNab criteria	72 patients (79%)
Nerubay (1997) (65)	32 (24–60)	Modified McNab criteria	
Choy (1998) (20)	84 (3–144) 350 patients	McNab criteria	80%
Gevargez (2000) (66)	1	Radicular or low back pain	
Knight (2002) (67)	60 (36–108)	Oswestry score: excellent or good (>50), satisfactory (>20)	
Gangi (communication, 2002)	29	McNab criteria	62%
Gronemeyer (2003) (71)	48 ± 16	Pain	169 patients (85%)
Tassi (2004) (68)	5 (max: 12)	McNab criteria	69 patients
Black (2004) (69)		McNab criteria	
McMillan (2004) (70)	3	AAOS score	

AAOS: American Academy of Orthopedic Surgery.

diameter, for transmission of laser energy in treating outpatients (21). The point of entry and the trajectory were identified by CT with the patient in the prone position, with a block under the abdomen to reduce lumbar lordosis. A lateral fluoroscopic view allows for verifying the angle and trajectory of the needle. General anesthesia is contraindicated, and a local anesthetic, which allows the patient to cooperate, is administered by use of a 22-gauge needle. An 18-gauge needle is placed parallel to the 22-gauge needle under fluoroscopic guidance. The patient is asked to report any pain in the lower limbs, which would necessitate repositioning the needle. The correct positioning of the needle (halfway between the 2 vertebral endplates, penetrating the annulus fibrosus [AF] and reaching the NP) is verified by CT. The optic fiber, connected to the laser source, is introduced into the disc, the distal part extending past the end of the 18-gauge needle by 5 mm.

Once the correct position has been reached, laser treatment can begin at 15 W, with pulses of 0.5 to 1 s and pauses of 4 to 10 s. The recommended doses are 1200 to 1500 J for L1-L2, L2-L3, L3-L4, and L5-S1, and 1500 to 2000 J for L4-L5. CT is performed every 200 J to visualize the area of vaporization. Pain can occur due to heat or

Table 4 Continued

Return to Work	% Success	Surgery	Complications
	4 asymptomatic (7–16 mo)	5/9 initially improved	No
"Most of patients"	78%: good or fair	72 patients (22%)	1 case
	53% (71% when all selection criteria)	39 patients	2 sympathetic dystrophy 12 dysesthesia
	Good (75%) or fair (15%) at 1 year; Good (72%) or fair (15%) at 2 years;		
	84% (187 patients: 117 excellent, 70 good)	10 patients	4: 1 septic discitis, 1 suspected discitis, 1 contralateral dermatomal discomfort, 1 transient nerve block
	75%: good or fair	33 patients	1%
		13 patients (6%)	8 (4%): 1 discitis, 7 back pain
59% at 4 weeks	66%: good or excellent; relief of radicular (72%) or low back pain (54%)		1 acute urinary retention
	87%: excellent or good	4%	
	76%: good or fair	7 patients	1 septic, 1 aseptic discitis, 1 phlebitis, 1 free-fragment migration
	74%: excellent or good	5 patients	4: root irritation by thermal damage
	75%: good or fair	6%	1% (5/518): 2 aseptic, 2 septic discitis, 1 retroesophageal abcess
	46%: >85% improvement of radicular pain; 31%: intermittent low back pain; 15%: slight improvement (<50%); 8%: no improvement		
	60 and 19% (1 year); 51 and 22% (3 years, 310 patients); 61% satisfied at 3 years		4 aseptic discitis
	76%	11%	4/412: 1 septic, 1 aseptic discitis, 1 phlebitis, 1 free-fragment migration
	Reduction or disappearance of pain: 73%		1 discitis
	83%: excellent or good	No	No
	88%: good (44%) or fair (44%)	No	No
	Mean improvement: 24/30 with radicular pain: 68%; 24/32 with discogenic pain: 44%	No	Development of worsening of low back pain in 20/32 (63%) patients during the 90-day study period

hyperpressure in the disc caused by accumulation of gas, which necessitates lengthening the pauses and performing aspiration. The needle and optic fiber are then withdrawn, and the patient can return first to the recovery room and then home, with instructions regarding the use of analgesics and nonsteroidal antiinflammatory drugs, rest for a few days, not being in positions of hyperkyphosis for 2 weeks, and restricted physical exercise. Physiotherapy is begun 3 weeks after the procedure, and the patient is seen again at 6 weeks.

Variations in this procedure have been reported. For example, Choy and coworkers used a 1064-nm Nd:YAG laser, with 20-W continuous energy, pulses of 1 s and pauses of 1 s, up to 1000 to 1850 J (for patients weighing more than 85 kg) (22). Davies used a KTP/532 laser, with 10 to 15 W continuous energy, pulses of 0.5 s and pauses of 0.5 s, up to 1250 J (51). Finally, Sherk and coworkers used a 2100-nm Ho:YAG laser, with 0.17 J per pulse up to 1200 to 1500 J (52). According to Choy the procedure lasts 30 minutes, and bed rest is recommended for 24 hours following discharge from hospital. Walking should commence after 2 to 3 days and patients can return to sedentary work after 6 days. Physiotherapy begins after 1 month and lasts for 6 weeks (53). Failure of the procedure for technical reasons is reported to be rare (about 1.5/1000 for 2535 PLDD) (54).

Indications, Complications, and Limitations

The indications for PLDD were summarized by Gangi and coworkers (Table 2) (21). All authors emphasize the strict respect for selection criteria to achieve a favorable outcome, which reduces the number of patients who can be treated with this technique (21,55,56). PLDD is an only slightly invasive technique and thus avoids the disadvantages of classical surgery (damage to lumbar muscles and soft tissue, duration of hospitalization, and convalescence), and the outcome is straightforward. Complications have included infectious and aseptic discitis, disc rupture, epidural hematoma, and damage to the AF or nerve root. Gangi and coworkers reported that low back pain persists or worsens temporarily in 60% of patients (21). A 0.5% complication rate was reported in a study of 3377 patients (57). Choy and coworkers reported 1 case of infectious discitis in 377 PLDDs (22), and Quigley reported 3 cases of abdominal perforation and 1 of partial cauda equina syndrome (18).

Evaluation of Effectiveness

Several series have been published (20,22,52,53,58-71) but no controlled studies are available (Tables 3 and 4). Most studies report a 75% success rate with PLDD (according to MacNab criteria; Table 5) (72), combining good (about 50%) and fair (about 25%) success rates, with 0.4 to 1% complications (particularly thermal and infectious discitis), and 5% recurrence.

Choy and coworkers reported on their initial experience with 12 patients in 1987 (15). In 9, radicular pain disappeared 2 minutes after the procedure; 5 required surgery for recurrence, the intervention revealing extruded disc fragments, and the remaining 4 were asymptomatic 7 to 16 months later. In 1992, the authors reported on the use of PLDD for 377 cases of disc herniation in 333 patients (22). According to the MacNab criteria, treatment in 261 (78%) was successful; the 72 failures (22%) were successfully treated with surgery, and one-third of the MRIs performed at 6 months showed slight or moderate reduction of herniation.

Ohnmeiss and coworkers studied the importance of selection criteria in 204 patients treated with a KTP/532 laser (55). Two independent evaluators reviewed the initial data and classified the patients into the 3 following groups: (1) selection criteria clearly verified; (2) selection criteria not verified; and (3) incomplete data. At a mean of 13 months after treatment, 164 patients (80%) were surveyed by questionnaire—41 (25%) in group 1; 42 (26%) in group 2; and 81 (49%) in group 3 (40 not contacted divided among the 3 groups). The success rate was significantly lower in group 2 (29%) than group 3 (56%) and particularly group 1 patients (71%) (for a total success rate of 53%), which emphasizes the importance of the selection criteria.

Liebler reported results with a KTP/532 in 117 patients; according to MacNab criteria, the success rate was good (75%) or fair (15%) in 90% of cases at 1 year, with rates of 72 and 15%, respectively, at 2 years (58). Casper and coworkers evaluated the Ho:YAG laser in 223 patients according to modified MacNab criteria (Table 6) (73). The success rate at 1 year (excellent or good) was 84% (59). The results at 2 years (by telephone interview) in 100 patients revealed a success rate of 87%, which was not influenced by sex, age, level of disc treated, duration of symptoms, existence of neurological disorders, secondary benefits, or history of spinal surgery (60). Choy and coworkers reported successful outcomes in 75% of 322

Table 5 MacNab Criteria of Success of Response to Treatment (72)

Good
Resumed preoperative function
Occasional backache or leg pain
No dependency-inducing medication, appropriate activity
No objective signs of nerve root damage
Fair
May be nonproductive if unchanged from preoperative status
Intermittent episodes of mild lumbar radicular pain or low back pain
No dependency-inducing medication
Appropriate activity
No objective signs of nerve root impairment
Poor
Subjective
No productivity
Continued pain behavior
Medication abuse
Inactive
Compensation or ligitation focus, or both
Objective
Signs of continuing radiculopathy

Table 6 Modified MacNab Criteria (73)

Success	
Excellent	Good
Pain free	Occasional nonradicular pain
No restriction of mobility	Relief of presenting symptoms
Able to return to normal work and activities	Able to return to modified work
Failure	
Fair	Poor
Some improved functional capacity	Continued objective symptoms of root involvement
Still handicapped and/or unemployed	Additional operative intervention needed at the index level, irrespective of length of postoperative follow-up

patients after 389 PLDDs, with a rate of complications of 1% (61). A questionnaire to 321 patients revealed 8 cases of complications (4%): 1 of discitis and 7 of low back pain, probably of thermal origin (62). Gangi and coworkers reported a successful outcome in 91 of 119 patients (77%), and reduction of the disc herniation on MRI or CT at 6 months in 61%. Follow-up of 50 patients treated with CO_2 laser showed a successful outcome in 74% (65). MRI or CT showed that the size of herniation was not changed in 58% of patients, was slightly reduced in 28%, and more clearly reduced in 14%, but was not associated with clinical outcome.

Among the large series investigating PLDD, the largest to date has been an open, nonrandomized study by Choy evaluating 752 cases of PLDD and involving use of a 1060-nm Nd:YAG in 518 patients. Such patients showed disc herniation on MRI, neurological involvement and/or Lasegue's sign, or failure of treatment after 3 months; all were candidates for surgery (20). Surprisingly, the statistical analysis included only the 350 patients treated between 1993 and 1998, which considerably reduces the value of the conclusions. Two levels of discs were treated in 56 patients, 3 levels in 15, 4 levels in 3, and 5 levels in 1. The overall success rate (good and fair by MacNab criteria) was 75%. The results were not influenced by age, sex, disc level treated, or duration of symptoms. The rate of complications was 1% (5/518 patients).

Knight and Goswami treated 576 patients with a 352-nm KTP (687 discs) for painful disc protrusion, rupture of the AF, or discogenic pain (discography reproducing the usual pain) (67). The authors achieved results of 60% excellent or good (Oswestry score >50) and 19% satisfactory (Oswestry score >20) at 1 year and 51 and 22%, respectively, at 3 years; 61% of patients were satisfied with the treatment at 3 years. Choy and coworkers evaluated PLDD in 32 patients with discogenic low back pain (pain on discography) (69). According to MacNab criteria, the results were good in 44%, fair in 44%, and poor in 12%. The fairly optimistic authors concluded that discogenic low back pain is a good indication for PLDD.

DISCUSSION

Analysis of published series raises several unresolved issues. This review of the literature related to PLDD for the treatment of lumbar disc herniation has revealed similar issues.

First, the methodology of many of the PLDD studies is questionable. The inclusion criteria are fairly homogeneous and acceptable but not other criteria. For example, in the largest series (20), the analysis was limited to patients selected on the basis of imprecise criteria. Authors provided detailed characteristics (age, sex, duration of follow-up, level treated) for the whole population (752 PLDD in 518 patients) and then, with no clear explanation, analyzed the results of only 350 patients. For other series, the evaluator was often the operator of the equipment; the evaluation criteria were not fully appropriate, and the fair results according to MacNab criteria were not convincing. Moreover, essentially 1 individual performs most of the procedures, and the technique may not be as successful in the hands of people inexperienced with a technique without specific indications or methods.

As well, no study has compared PLDD with discectomy; indeed, despite the short-term success rate of 80 to 90% for discectomy, the long-term success rate is 40 to 80% (74-77) and reintervention rates are reported to be between 5 and 25% (75,78-80). If the efficacy of PLDD is demonstrated, the technique would be an exciting alternative to discectomy because of its short duration of intervention (15 to 30 minutes) and short time for convalescence and absence from work.

Above all, 20 years after the first PLDD, a controlled study of the technique is still lacking. A randomized controlled trial is necessary to compare PLDD with discectomy in patients, particularly investigating the inclusion criteria listed in Table 2.

Finally, the premature validation and widespread use of this attractive and only slightly invasive technique run the risk of inappropriate extension of indications for its use, as suggested by the most recently published series (69,70). These studies included patients with discogenic low back pain diagnosed on discography, and the reliability of PLDD for this condition is questionable.

Although the concept of laser nucleotomy is tempting for use in treating lumbar herniated disc, many unresolved issues remain regarding equipment (optimal wavelength, duration of application, quantity of energy delivered), the precise mechanism of action, and possible untoward effects on the intervertebral disc. Therefore, PLDD could be used as an alternative to classical surgery. However, in light of results of the open studies published to date, which involve weak methodology, and the absence of controlled trials, its use as a validated treatment for disc herniation-related radiculopathy resistant to medical treatment is questionable.

REFERENCES

1. Simmons JW, Nordby EJ, Hadjipavlou AG. Chemonucleolysis : the state of the art. Eur Spine J 2001;10:192-202.
2. Suguro T, Degema JR, Bradford DS. The effects of chymopapain on prolapsed human intervertebral disc. Clin Orthop 1986;213: 223-31.
3. Smith L, Garvin PJ, Jennings R, Gesler RM. Enzyme dissolution of the nucleus pulposus. Nature 1963;98:1311-2.
4. Dabezies EJ, Langford K, Morris J, Shields CBN Wilkinson HA. Safety and efficacy of chymopapain (Discase) in the treatment of sciatica due to herniated nucleus pulposus. Results of a randomized, double-blind study. Spine 1988;13:561-5.
5. Feldman J, Menkes CJ, Pallardy G, Chevrot A, Horreard P, Zenny JC, et al. Double-blind study of the treatment of disc lumbosciatica by chemonucleolysis. Rev Rhum Engl Ed 1986; 53:147-52.

6. Fraser RD. Chymopapain for the treatment of intervertebral disc herniation: a preliminary report of a double-blind study. Spine 1982;7:608-12.
7. Javid MJ, Nordby EJ, Ford LT, Hejna WJ, Whisler WW, Burton C, et al. Safety and efficacy of chymopapain (Chymodiactin®) in herniated nucleus pulposus with sciatica: results of a randomized, double-blind study. JAMA 1983;249:2489-94.
8. Schwetschenau PR, Ramirez A, Johnston J, Wiggs C, Martins AN. Double-blind evaluation of intradiscal chymopapain for herniated lumbar discs. Neurosurgery 1976;45:622-7.
9. Hijikata S. Percutaneous nucleotomy. A new concept technique and 12 years' experience. Clin Orthop 1989;238:9-23.
10. Onik G, Helms CA, Ginsberg L, Hoaglund FT, Morris J. Percutaneous lumbar diskectomy using a new aspiration probe : porcine and cadaver model. Radiology 1985;155:251-2.
11. Mochida J, Toh E, Nomura T, Nishimura K. The risks and benefits of percutaneous nucleotomy for lumbar disc herniation. A 10-year longitudinal study. J Bone Jt Surg 2001;83B:501-5.
12. Onik G, Maroon J, Helms C, Schweigel J, Mooney V, Kahanovitz N, et al. Automated percutaneous diskectomy: initial patient experience. Radiology 1987;162:129-32.
13. Davis GW, Onik G, Helms CA. Automated percutaneous discectomy. Spine 1991;16:359-63.
14. Revel M, Payan C, Vallée C, Laredo JC, Lassale B, Roux C, et al. Automated percutaneous lumbar discectomy versus chemonucleolysis in the treatment of sciatica. A randomized multicenter trial. Spine 1993;18:1-7.
15. Choy DSJ, Case RB, Fielding W, Hughes J, Liebler W. Percutaneous laser nucleolysis of lumbar disks. N Engl J Med 1987;317:771-2.
16. Choy DSJ. The true story of percutaneous laser disc decompression. J Clin Laser Med Surg 2001;19:231-3.
17. Quigley MR, Maroon JC. Laser discectomy: a review. Spine 1994;19:53-6.
18. Quigley MR. Percutaneous laser discectomy. Neurosurg Clin N Am 1996;7:37-42.
19. Choy DS. Percutaneous laser disc decompression: an update. Photomed Laser Surg 2004;22:393-406.
20. Choy DS. Percutaneous disc decompression (PLDD): twelve year's experience with 752 procedures in 518 patients. J Clin Laser Med Surg 1998;16:325-31.
21. Gangi A, Dietemann JL, Ide C, Brunner P, Klinkert A, Warter JM. Percutaneous laser disk decompression under CT and fluoroscopic guidance: indications, technique, and clinical experience. Radiographics 1996;16:89-96.
22. Choy DS, Ascher PW, Ranu HS, Saddeknis S, Alkaitis D, Liebler W, et al. Percutaneous laser disc decompression. A new therapeutic modality. Spine 1992;17:949-56.
23. Yonezawa T, Onomura T, Kosaka R, Miyaji Y, Tanaka S, Watanabe H, et al. The system and procedures of percutaneous intradiscal laser nucleotomy. Spine 1990;15:1175-85.
24. Gottlob C, Kopchok GE, Peng SK, Tabbara M, Cavaye D, White RA. Holmium:YAG laser ablation of human intervertebral disc: preliminary evaluation. Lasers Surg Med 1992;12:86-91.
25. Quigley MR, Shih T, Elrifai A, Marron C, Lesiecki ML. Percutaneous laser discectomy with the Ho:YAG laser. Lasers Surg Med 1992;12:621-4.
26. Davis JK. Percutaneous discectomy improved with KTP laser. Clin Laser Mon 1990;8:105-6.
27. Choy DSJ, Altman PA, Case RB, Trokel SL. Laser radiation at various wavelenghts for decompression of intervertebral disk. Experimental observations on human autopsy specimens. Clin Orthop 1991;267:245-50.
28. Sato M, Ishihara M, Arai T, Asazuma T, Kikuchi T, Thayashi T, et al. Use of a new ICG-dye-enhanced diode laser for percutaneous laser disc decompression. Lasers Surg Med 2001;29:282-7.
29. Buchelt M, Schlangmann B, Schmolke S, Siebert W. High power Ho:YAG laser ablation of intervertebral discs: effects on ablation rates and temperature profile. Lasers Surg Med 1995;16:179-83.
30. Min K, Leu H, Zweifeld K. Quantitative determination of ablation in weight of lumbar intervertebral discs with holmium:YAG laser. Lasers Surg Med 1996;18:187-90.
31. Schlangmann B, Schmolke S, Siebert W. Temperature and ablation measurements in laser therapy of intervertebral disk tissue. Orthopade 1996;25:3-9.
32. Marron JC, Allen RC. A retrospective study of 1054 APLD cases: a twenty-month clinical follow-up at 35 US centers. J Neurol Orthop Med Surg 1989;10:335-7.
33. Yonezawa T, Tanaku S, Watanabe H, Onomura T, Atsumi K. In: Mayer HM, Brock M, eds., Percutaneous Intradiscal Laser Discectomy: Percutaneous Lumbar Discectomy, 1st ed. Heidelberg, Springer Verlag, 1989:197-204.
34. Choy DS, Diwan S. In vitro and in vivo fall of intradiscal pressure with laser disc decompression. J Clin Laser Med Surg 1992;10:435-7.
35. Choy DSJ, Altman P. Fall of intradiscal pressure with laser ablation. J Clin Laser Med Surg 1995;13:149-51.
36. Case RB, Choy DSJ, Altman P. A change of intradisc pressure versus volume change. J Clin Laser Med Surg 1995;13:143-7.
37. Goupille P, Mulleman D, Valat JP. Radiculopathy associated with disc herniation. Ann Rheum Dis 2006;65:141-3.
38. Iwatsuki K, Yoshimine T, Sasaki M, Yasuda K, Akiyama C, Nakahira R. The effect of laser irradiation for nucleus pulposus : an experimental study. Neurol Res 2005;27:319-23.
39. Turgut M, Önol B, Kilinic K, Tahta K. Extensive damage to the end-plates as a complication of laser discectomy. An experimental study using an animal model. Acta Neurochir 1997;139:404-10.
40. Turgut M, Sargin H, Önol B, Acikgoz B. Changes in end-plate vascularity after Nd:YAG laser application to the guinea pig intervertebral disc. Acta Neurochir 1998;140:819-25.
41. Anzai Y, Lufkin RB, Castro DJ, Farahani K, Jabour BA, Layfield JJ, et al. MR imaging-guided interstitial Nd:YAG laser phototherapy: dosimetry study of acute tissue damage in an in vivo model. J Magn Reson Imaging 1991;1:553-9.
42. Phillips JJ, Kopchok GE, Peng SK, Mueller MP, White RA. MR imaging of Ho:YAG laser diskectomy with histologic correlations. J Magn Reson Imaging 1993;3:515-20.
43. Tonami H, Yokota H, Nakagawa T, Higashi K, Okimura T, Yamamoto I, et al. Percutaneous laser discectomy: MR findings within the first 24 hours after treatment and their relationship to clinical outcome. Clin Radiol 1997;52:938-44.
44. Cvitanic OA, Schimandle J, Casper GD, Tirman PF. Subchondral marrow changes after laser diskectomy in the lumbar spine: MR imaging findings and clinical correlation. AJR Am J Roentgenol 2000;174:1363-9.
45. Black JD, Sherk HH, Rhodes ABL, Smith RC. Anterior cervical discectomy using Ho:YAG laser. Surg Forum 1990;41:527-30.
46. Quigley MR, Shih T, Elrifai A, Maroon JC, Lesiecki ML. Percutaneous laser discectomy with the Ho:YAG laser. Lasers Surg Med 1992;12:621-4.
47. Turgut M, Ozcan OE, Sungur A, Sargin H. Effect of Nd:YAG laser on experimental disc degeneration. Part II. Histological and MR imaging findings. Acta Neurochir 1996;138:1355-61.
48. 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.
49. Gangi A, Kastler B, Dietemann JL. Percutaneous vertebroplasty guided by a combination of CT and fluoroscopy. AJNR Am J Neuroradiol 1994;15:83-6.
50. Seibel RMM, Grönmeyer DHW, Sörensen SAL. Percutaneous nucleotomy with CT and fluoroscopic guidance. JVIR J Vasc Interv Radiol 1992;3:571-6.

51. Davies JK. Early experience with laser disc decompression. J Fla Med Assoc 1992;79:37-9.
52. Sherk HH, Rhodes A, Black J, Prodoehl JA. Results of percutaneous lumbar discectomy with lasers. In: Sherk HH, ed., Spine: State of the Art Reviews Laser Discectomy. Philadelphia, Hanley & Belfus, 1993:141-50.
53. Choy DS. Techniques of percutaneous laser disc decompression with the Nd:YAG laser. J Clin Laser Med Surg 1995;13:187-93.
54. Hellinger J. Technical aspects of the percutaneous cervical and lumbar laser-disc-decompression and -nucleotomy. Neurol Res 1999;21:99-102.
55. Ohnmeiss DD, Guyer RD, Hochschuler SH. Laser disc decompression. The importance of proper patient selection. Spine 1994; 19:2054-9.
56. Choy DS, Botsford J, Black WA Jr. Patient selection: indications and contraindications. J Clin Laser Med Surg 1995;13:157-9.
57. Hellinger J. Complications of non-endoscopic percutaneous laser disc decompression and nucleotomy with the neodymium:YAG laser 1064 nm. Photomed Laser Surg 2004;22:418-22.
58. Liebler WA. Percutaneous laser disc nucleotomy. Clin Orthop 1995;310:58-66.
59. Casper GD, Mullins LL, Hartman VL. Laser-assisted disc decompression: a clinical trial of holmium:YAG laser with side-firing arm. J Clin Laser Med Surg 1995;13:27-31.
60. Casper GD, Hartman VL, Mullins LL. Results of a clinical trial of the holmium:YAG laser in disc decompression utilizing a side-firing fiber: a two-year follow-up. Laser Surg Med 1996;19:90-6.
61. Choy DS. Clinical experience and results with 389 PLDD procedures with the Nd:YAG laser, 1986 to 1995. J Clin Laser Med Surg 1995;13:209-13.
62. Chambers RA, Botsford JA, Fanelli E. The PLDD registry. J Clin Laser Med Surg 1995;13:215-9.
63. Bosacco SJ, Bosacco DN, Berman AT, Cordover A, Levenberg RJ, Stellabotte J. Functional results of percutaneous laser discectomy. Am J Orthop 1996;25:825-8.
64. Siebert WE, Berendsen BT, Tollgaard J. Percutaneous laser disk decompression. Experience since 1989. Orthopade 1996;25:42-8.
65. Nerubay J, Caspi I, Levinkopf M. Percutaneous carbon dioxide laser nucleolysis with 2- to 5-year follow-up. Clin Orthop 1997; 337:45-8.
66. Gevargez A, Groenemeyer DWH, Czerwinski F. CT-guided percutaneous laser disc decompression with Ceralas-D, a diode laser with 980-nm wavelength and 200-μm fiber optics. Eur Radiol 2000;10:1239-41.
67. Knight M, Goswami A. Lumbar percutaneous KTP^{532} wavelength laser disc decompression and disc ablation in the management of discogenic pain. J Clin Laser Med Surg 2002;20:9-13.
68. Tassi GP. Preliminary Italian experience of lumbar spine percutaneous laser disc decompression according to Choy's method. Photomed Laser Surg 2004;22:439-41.
69. Black W, Fejos AS, Choy DS. Percutaneous laser disc decompression in the treatment of discogenic back pain. Photomed Laser Surg 2004;22:431-3.
70. McMillan MR, Patterson PA, Parker V. Percutaneous laser disc decompression for the treatment of discogenic lumbar pain and sciatica: a preliminary report with 3-month follow-up in a general pain clinic population. Photomed Laser Surg 2004;22:434-8.
71. Gronemeyer DH, Buschkamp H, Braun M, Schirp S, Weinsheimer PA, Gevargez A. Image-guided percutaneous laser disk decompression for herniated lumbar disks: a 4-year follow-up in 200 patients. J Clin Laser Med Surg 2003;21:131-8.
72. MacNab I. Negative disc exploration: an analysis of the causes of nerve-root involvement in sixty-eight patients. J Bone Joint Surg Am 1971;53:891-903.
73. MacNab I. The traction spur: an indicator of segmental instability. J Bone Joint Surg Am 1971;53:663-70.
74. Loupasis GA, Stamos K, Katonis PG, Sapkas G, Korres DS, Hartofilakidis G. Seven-to 20-year outcome of lumbar discectomy. Spine 1999;24:2313-7.
75. Davis RA. A long-term outcome analysis of 984 surgically treated herniated lumbar discs. J Neurosurg 1994;80:415-21.
76. Yorimitsu E, Chiba K, Toyama Y, Hirabayashi K. Long-term outcomes of standard discectomy for lumbar disc herniation. Spine 2001;26:652-7.
77. Findlay GF, Hall BI, Musa BS, Oliveira MD, Fear SC. A 10-year follow-up of the outcome of lumbar microdiscectomy. Spine 1998;23:1168-71.
78. Vik A, Zwart JA, Hulleberg G, Nygaard OP. Eight year outcome after surgery for lumbar disc herniation: a comparison of reoperated and not reoperated patients. Acta Neurochir 2001; 143:607-11.
79. Atlas SJ, Keller RB, Chang Y, Deyo RA, Singer DE. Surgical and non surgical management of sciatica secondary to a lumbar disc herniation. Five-year outcomes from the Maine lumbar spine study. Spine 2001;26:1179-87.
80. Malter AD, McNeney B, Loeser JD, Deyo RA. Five-year reoperation rates after different types of lumbar spine surgery. Spine 1998;23:814-20.