Lasers in percutaneous disc surgery

Beneficial technology or gimmick?

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Since the clinical introduction of 'percutaneous nucleotomy' by Hijikata in 1975, a variety of surgical techniques has been developed for what can be summarized under the term 'percutaneous disc surgery' (17, 18, 19, 23, 24, 49, 36, 37, 53, 54, 58). These procedures aim to remove a herniated lumbar disc through a percutaneous, posterolateral approach to the intervertebral space. The fact that the disc space is reached at an angle between 45° and 60° to the sagittal plane implies certain technical requirements concerning the design of the instruments which must enable the surgeon to either decompress the disc space or even selectively remove nucleus pulposus from the site of herniation.

The current techniques can be divided into two groups (Table 1): nonendoscopic and endoscopic methods. Both groups have initially been performed with manual and/or automated instruments. The search for technical improvement as well as the increasing popularity of medical laser systems soon led to different applications of laser technology in percutaneous disc surgery. However, the fascination of the laser as a surgical tool bears the risk of uncritical application and overuse. The aim of this article is to give a survey of the current knowledge on lasers in percutaneous disc surgery.

Methods for percutaneous disc surgery (Table 1)

The surgical goal of non-endoscopic techniques is to achieve an 'internal disc decompression' by removal of parts of the nucleus pulposus from the center of the disc space without visual control (47, 50). They are indicated in contained disc herniations ('protrusions').

The endoscopic procedures are multiinstrumental methods (anulus trephines, straight, flexible and reverse opening rongeurs, shavers, cutters) and are characterized by the use of endoscopes in the intervertebral space ('discoscopy') either for intermittent or permanent control of the surgical procedure (26, 31, 36, 44, 54). The aim of these techniques is selective nucleectomy in the posterior part of the disc space. They are indicated in contained as well as in non-contained disc herniations (26, 36, 44, 31, 54; Table 2).

Endoscopic techniques for selective nucleectomy:

- Percutaneous nucleotomy with discoscopy (PN; 31, 53, 54)
- Percutaneous endoscopic discectomy (PED; 36, 44)
- Arthroscopic microdiscectomy (AMD; 25, 26, 27)

These techniques show only slight differences in the kind of instruments used. Their common goal is the selective removal of the herniated parts of the nucleus pulposus in the posterior third of the disc space. They can be performed through a posterolateral approach

Table 1. Percutaneous disc surgery

Endoscopic techniques with and without laser	
PN	Percutaneous nucleotomy with discoscopy
PED	Percutaneous endoscopic discectomy
AMD	Arthroscopic microdiscectomy
Nonendoscopic techniques without laser	
APLD	Automated percutaneous lumbar discectomy
PF	Percutaneous disc fenestration
Nonendoscopic techniques with laser	
PLDD	Percutaneous laser disc decompression

Table 2. Indications for percutaneous discectomy

Clinical
Discogenic sciatica
Radicular sensory deficits
Radicular motor weakness (Grade III–V)
Unsuccessful conservatice therapy
Morphological
Contained disc herniations (protrusion)
Noncontained disc herniation (prolapse)[a]
• posterior longitudinal ligament intact
• in level of disc space
• occupying not more than 30 % of of the spinal canal
• not sequestrated

[a]only endoscopic methods

either from one or from both sides. The instruments (straight, flexible, up-biting, reverse opening rongeurs, shavers, cutters) can be directed to this target-area within the intervertebral space under visual control with angled 30°–90° endoscopes ('Discoscopy'). Effectiveness, good overall results in 75–85% as well as a low complication rate for these techniques have been published recently (26, 37, 44, 54).

Nonendoscopic techniques for intradiscal decompression:

- Automated percutaneous lumbar discectomy (APLD; 34, 35, 49, 50)
- Percutaneous fenestration (PF; 47)

These techniques are characterized as 'one-instrument-methods'. Nucleus pulposus is removed from the center of the disc either by a Nucleotome™ (34, 50), or by an anulus trephine and a forceps (47). Since the instruments are straight and rigid, only parts of the nucleus pulposus from the center of the disc space can be removed. Thus, an internal disc decompression is achieved. Clinical success rates for APLD have been reported to be more than 75 % (12, 35, 50). However, in a recent multicenter study, it has been proven less effective (22) and its indications should be restricted to contained disc herniations/protrusions (7) (Table 2). The method of percutaneous disc fenestration is associated with a high complication rate (41, 47).

The laser

The word LASER is an acronym for Light Amplification by Stimulated emission of Radiation. This kind of electromagnetic radiation is created by external stimulation of a laser medium which has been put into a condition termed population inversion. This active laser medium can be solid material (e.g. ruby crystal), gas (e.g. helium neon), dyes (e.g. rhodamine) or semiconductor material like gallium arsenide (1). Laser light is characterized by three qualities: it is monochromatic, coherent and collimated. The laser-tissue-interaction in biological tissues is determined by the physical properties of the laser (wavelength, pulse-length, applied energy or energy density) and on the other hand by the optical, mechanical, biochemical and physiological characteristics of the tissue (absorption, scattering, reflection, tissue structure and density, heat conduction etc.). To predict the effects of a certain laser on a certain tissue, it is necessary to have information about these variables. A variety of effects and defects can thus be created with one single laser system (e.g. welding, drying, coagulation, carbonization, vaporization, ablation). They range from simple photochemical processes to so-called non-linear effects which start at power-densities of 10^7 W/cm^2 and exposure-times in the order of nanoseconds (1).

Table 3. Optical characteristics of nucleus pulposus tissue according to Vorwerk et al 1989 (60), percent

Laser	nm	Absorption	Scattering	Reflection
KrF	248	64	24	14
XeCl	308	60	25	15
XeF	351	59	26	16
KTP	532	38	36	26
Nd:YAG	1064	31	39	30
Nd:YAG	1318	58	26	16
Ho:YAG	2100	83	11	6

The most well known laser effects however are thermal actions such as coagulation, carbonization or vaporization of tissue.

Laser-tissue interaction with nucleus pulposus

The absorption spectrum of nucleus pulposus is comparable to other non-vascularized biological tissues (39). It shows unspecific absorption peaks in the ultraviolet range (e.g. at 262 nm and 272 nm) as well as in the near and far infrared range of wavelengths (at 2900, 3200, and 6100 nm). The latter peaks represent the absorption of these wavelengths by the water contained in the tissue. The absorption bands in the ultraviolet range are due to peptide bonds (175, 190, 210-220 nm) or amino acids like phenylalanine (250 nm), histidine, cystine (260 nm), tyrosine (274 nm) or tryptophane (280 nm) (5). The behavior of nucleus pulposus is in this respect unspecific since other biological tissues with comparable water content show comparable absorption characteristics (13, 63). This means that the best ablative effects on disc tissue can be obtained with laser-wavelengths which are in the range of the described absorption peaks. A summary of the absorption, reflection and scattering characteristics of degenerated nucleus pulposus to different common medical lasers is given in Table 3 (60).

Lasers for percutaneous disc surgery (Table 4)

Ultraviolet wavelengths

The XeCL-EXCIMER 308 nm; The EXCIMER Laser (EXCIted DiMERs) is a pulsed gas-laser which emits light of wavelengths between 157–351 nm. The laser medium is a mixture of a halogen with an inert gas (e.g. Xenon/Chloride, Argon/Fluoride). The laser pulses are short (10-n x 100 nanoseconds) and the repetition-rate can reach up to 1000 Hz. The most commonly used wavelength is 308 nm emitted by the XeCL-Excimer-laser. Due to the high energy density

Table 4. Characteristics of laser systems for percutaneous discectomy

Laser	nm	Fiber	Ablation of disc tissue	Ablation velocity	Carbonization
XeCl	308	+	++	(+)	-
KTP	532	+	+	+	++
Nd:YAG	1064/1318	+	+	+(+)	++
Ho:YAG	2100	+	++	++	(+)
Er:YAG	2940	–	+++	++	–

which is achieved on the tissue surface, this laser light initiates the non-linear process of photoionization which means, that the molecular bonds of the tissue are disrupted, and the irradiated volume is ablated in a microexplosion (6, 57). Since the ablation process proceeds very rapidly, there are virtually no thermal side effects. For this reason, the Excimer-Laser was mainly used in ophthalmology and angiology (15, 16, 20, 21, 65). It has been shown in experimental studies, that its effects on human disc material can be predicted and controlled. Nucleus pulposus can be ablated with negligible thermal damage (40, 64). It can be transmitted through flexible quarz-fibers and can be used in an aqueous medium. However, the main disadvantages still are the low radiation powers (which make the ablation process time-consuming), the mutagenic and carcinogenic potential and the excessive costs. For this reason there have been only rare clinical applications (30).

Visible wavelengths

The KTP 532-nm Laser; The device uses a potassium titanyl phosphate (KTP) crystal to produce laser light which is visible ('green') with a wavelength of 532 nm. Their has been mainly clinical experience with this laser-type in various surgical specialties mainly for cutting and coagulating tissue (45). The absorption characteristics are shown in Table 3. Since there is no absorption peak of nucleus pulposus at 532 nm, the action of this laser is thermic. Disc tissue exposed to 0.5 sec pulses of 15 W shows thermal damage zones of less than 0.9 mm (11). Although there has been virtually no experimental scientific background, it has been introduced for non-endoscopic percutaneous discectomy (10, 11, 45, 46).

Infrared wavelengths

The Neodymium:YAG 1064/1318-nm Lasers; These are the most widely used medical laser systems. The laser wavelengths of 1064 or 1318 nm are emitted by neodymium embedded in an Yttrium-Aluminum- Garnet crystal. The absorption of 1064 and 1318 nm by biological tissue is low. The scattering effect is thus pronounced and leads to a distribution of the applied energy within the tissue. The penetration depth in cartilaginous tissue can reach up to 6 mm, however with controlled application of powers between 20–40 W and pulses of 0.05-0.1 sec, the coagulation zone can be reduced to 0.6 mm with a contact probe (2, 3, 14, 51). It has been proven to be efficient for coagulation and removal of lumbar disc tissue in experimental and clinical studies (3, 4, 38, 42, 43, 52). The advantages of this laser are: fiberoptic delivery, usage in dry and aqueous media, coagulation and hemostasis are possible. The disadvantages are: heat generation and energy transmission through the tissue, risk of tip breakage and the costs although these have dropped within the last years.

The Holmium:YAG 2100-nm Laser; This laser is a pulsed near-infrared laser and creates light of the wavelength 2100 nm (28). It is absorbed mainly by tissue-water (Table 3). The laser delivers a 400 μsec long envelope of 1-μsec pulses. The repetition rate is 1–20 Hz, the pulse energy can be varied from 0 to 2 J. The application on cartilaginous tissues leads to an 'instant vaporization' which allows its precise removal. The thermal effects are smaller as compared to the Nd:YAG Lasers. The reported clinical applications in arthroscopic surgery as well as in percutaneous discectomy procedures are yet limited but promising (33, 55, 56). The main advantages are: fiberoptic delivery, usage in dry and aqueous media, 0.4-0.6-mm thermal damage zone in cartilaginous tissue, hemostasis, coagulation, and vaporization possible. Moreover it can be used in arthroscopic as well as in disc surgery. The disadvantages still are the high costs and the low power range which might prolong surgery.

The Erbium:YAG 2940-nm Laser; The Er:YAG is a solid laser which contains ions of Erbium embedded in an Yttrium-Aluminum-Garnet crystal. It is able to deliver micropulses of laser light with a duration of 1–340 μsec/pulse (61, 62). The emitted wavelength is 2940 nm, energy densities of 500 mJ/mm^2 can be achieved. The ablation threshold for nucleus pulposus

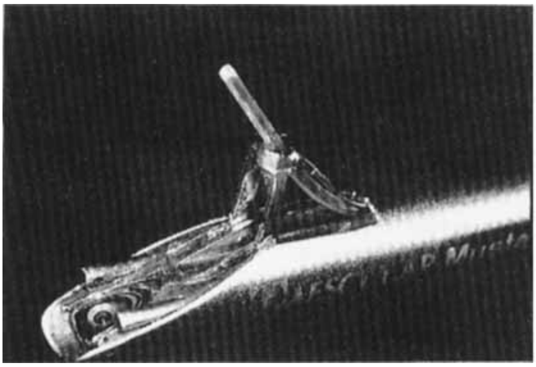

Figure 2. Instruments for percutaneous endoscopic laser assisted discectomy (PELD).

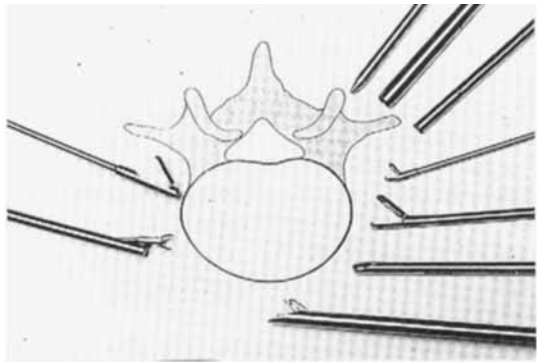

Figure 2. Universal laser applicator for percutaneous endoscopic laser-assisted discectomy (OD 5.6 mm, 200–400-µ quarz fiber, 80° deflection, 70° optical system, irrigation and suction channels.

is 7 mJ/mm^2 (39). It is excellently absorbed by tissue-water and has also been used for experimental osteotomies (48). In experimental studies, this laser offers the advantage of efficient ablation of nucleus pulposus (e.g. 5 grams of nucleus pulposus can be removed within 30 minutes) with only thermal damage zones < 0.5 mm (39). It is safe, since the effects are predictable according to the parameters used. Despite these qualities, it can currently not be used in an endoscopic technique since no safe and adequate flexible light transmission is available. However, it seems to be a promising device for the future.

The clinical application of lasers in percutaneous disc surgery

Percutaneous endoscopic laser assisted discectomy (PELD); This method has been introduced by the senior author in August 1989. The technique as well as first preliminary results have been published recently (42,43). The surgical goal of PELD is the decompression of the lumbar spinal nerve by selective endoscopic removal of the herniated parts of the nucleus pulposus. This required the combined use of manual (trephines, straight-, flexible-, and reverse-opening forceps) and automated (shavers, cutters) instruments with Laser technology (Figure 1). The indication for this procedure is identical with the one described for PED (see above).

Technique; The disc space is reached through a posterolateral approach (uni- or bilateral) in local anesthesia with the patient in a prone position. A working cannula (OD: 4-6 mm) is placed at the posterolateral border of the anulus fibrosus under fluoroscopic control. The anulus is perforated with trephines and only small parts of the nucleus pulposus are removed from the center of the disc. Under video-endoscopic control through a 70° angled endoscope, the herniated parts of the nucleus pulposus are removed selectively from the posterior third of the intervertebral space. This is achieved with flexible and reverse opening forceps as well as with a Nd:YAG 1064-Laser which energy is transmitted through a flexible and directable quarz fiber. Single shots are delivered in 0.05–0.1-sec pulses with an application power between 20–30 W. An average of 500–600 J per disc is applied. The procedure is completed when no more loose nucleus pulposus is visible in the posterior third of the disc space.

Results (Table 5); In our first series, a total of 40 patients (24 men, 16 women, aged 40 (12–55) years) have been treated with PELD. 39 of the procedures were at L4/5 and one at L3/4. Before the operation, all patients except one had low back pain and all had radicular sciatica which was permanent in 39 cases and stress-induced in one. 25 patients had sensory disturbances, and 3 had mild motor weakness but patients with rapidly progressing or severe motor deficits had been excluded from the series. Following PELD with a minimum follow-up of 2 years, 33 patients (including 2 reoperated on cases) were without sciatica. However, from the remaining 7 patients, only 5 still complained of sciatica in a dermatomal distribution. Sensory disturbances had disappeared in 27/40 patients (including 3 reoperated) while no patient was left with a motor deficit. 4 patients had to be reoperated on by microsur-

Table 5. Results of PELD, patients

	Excellent	Good	Fair	Poor
PELD	15	9	9	3
Surgery after PELD	1	3	0	0

gery because of persistent or recurrent clinical symptoms. Except for 3 patients who had been disabled for reasons other than the disc herniation, all other patients had returned to their preoperative work. There were no complications.

Meanwhile, the endoscopic use of Nd:YAG, Holmium-, Excimer- or KTP-lasers have been reported (29, 30, 27, 33, 52). In our experience, the endoscopically guided laser application offers advantages in the removal of nucleus pulposus from the target area in the posterior part of the disc space.

Nonendoscopic percutaneous laser disc decompression (PLDD); This technique was first described by Choy and Ascher in 1986 and by Ascher in 1988 (3, 8, 9). The surgical goal of PLDD is the internal decompression of the disc. This is achieved with coagulation and shrinking of central parts of the nucleus pulposus by the applied laser energy. The tip of an 18 gauge-cannula is placed into the center of the lumbar disc space under fluoroscopic control via a posterolateral approach. Laser-light is then applied to the nucleus through a 400–600-μ quarz-fiber introduced through the cannula. The applied energy is 1–2 kJ per disc in 1-sec pulses of 20 W with 3–4-sec intervals (9).

Clinical experience with different lasers used with this obviously simple technique is accumulating rapidly (3, 4, 8, 9, 32). The indication spectrum however seems to be not well defined. The procedure is performed in patients with radicular pain or low back pain with correlating CT and/or MRI findings (8, 9). An exclusion of nondiscogenic low back pain is neither required nor is conservative therapy in the hospital (8, 9). The success rates are reported to be 70–75% with follow-up periods of between 12 and 75 months (3, 9, 32).

Conclusion

What is available? There are different laser systems (Excimer 308, KTP 532, Nd:YAG 1064/1318, Holmium:YAG 2100, Erbium:YAG 2940) which are able to coagulate, shrink, carbonize, vaporize or ablate nucleus pulposus tissue. This has been proven in numerous experimental studies. The lasers differ in application parameters and the mode of laser-tissue interaction. Percutaneous disc surgery has been clinically performed with the Excimer, the KTP, the Nd:YAG and the Holmium.

What has been done? The laser has been introduced in percutaneous procedures with different aims: In endoscopic disc surgery, it serves as an additional surgical instrument to the manual and automated equipment. In our experience it seems to be at least as efficient as flexible forceps for the removal of nucleus from the posterior third of the disc space. With the laser, these parts of the nucleus pulposus can be coagulated or selectively removed. It seems to be at least as safe as manual instruments provided a correct application with adequate parameters. Clinical experience has mainly been accumulated with the Nd:YAG 1064 nm-Laser although other lasers such as Excimer or Holmium have also been used in endoscopic procedures (30, 33).

In nonendoscopic disc surgery, the laser has been used instead of manual or automated instruments. Internal disc decompression through coagulation of the nucleus pulposus is achieved. It seems to be at least as safe as comparable manual techniques like automated percutaneous lumbar discectomy (APLD). The efficiency is hard to define since the indication spectrum obviously includes patients which could as well be considered nonsurgical candidates. On the other hand, the mechanism of pain relief is not well understood. Postoperative radiological findings do not correlate with the clinical result.

What is proven? Clinical experience with lasers in percutaneous disc surgery accumulates rapidly. Most of the reported data are not even controlled studies but mere empirical data. Although it might be fascinating and beneficial to include the laser technology in this kind of procedure, it has to be compared with the established techniques and stand the following questions:

Is it more efficient? There is no study which has proven, that the use of lasers for intradiscal decompression is superior to automated percutaneous lumbar discectomy (APLD) or to chemonucleolysis. Concerning the clinical result, there is no proven superiority of laser-assisted- compared to endoscopic discectomy without laser.

Is it faster, safer or more simple? There is no study with reliable data on these factors. However, our own experience shows that the laser does not shorten the operating time. It is certainly not safer since an additional tool like the laser statistically means an additional risk. However, up to now, there are no laser-specific complications described. Finally, it is not more simple than manual techniques.

Is it less traumatizing? In PELD, postoperative MRI of the treated discs did not show any evidence of thermal damage to the endplates or to structures surrounding the intervertebral space (own unpublished data).

Are the clinical results superior as compared to established techniques? Our experience with PELD revealed success-rates comparable to the nonlaser cases. However, the indication spectrum could be enlarged and noncontained disc herniations have been included in the series.

So what has been proven is the fact, that certain lasers are able to coagulate or vaporize nucleus pulposus tissue in a way which does not lead to alterations of the structures surrounding the disc space.

What has to be done? There is a large gap between the number of scientific studies including clinical studies and the amount of empirical data on the clinical use of Lasers in percutaneous disc surgery. There is a need for controlled prospective clinical studies to definitely answer the questions stated above. These studies should be initiated and performed by centers experienced in percutaneous disc surgery.

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