CHAPTER 29

Laser

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INTRODUCTION

Although many patients benefit from surgical discectomy with or without a fusion these open procedures are associated with known risks, including early or late failures secondary to symptomatic adhesions, pseudoarthrosis, and adjacent level instability. These complications have prompted the development and introduction of less invasive percutaneous intradiscal procedures that have the ability to chemically or mechanically remove intradiscal nuclear material. Chemonucleolysis using the intranuclear injection of chymopapain was introduced several decades ago and a variety of other intradiscal and endoscopic procedures have followed. Among the intradiscal procedures are nucleoplasty (coblation), automated percutaneous lumbar discectomy using the nucleotome, and decompression.

Most of the devices removed nuclear material using mechanical incision by surgical instruments or suction, but in 1986 Choy et al.[1] introduced nonendoscopic percutaneous laser disc decompression and nucleotomy with the Nd:YAG laser (wavelength 1064 nm). Even though the 1064 nm wavelength Nd:YAG laser technique has been mostly supplanted by soft laser technology,[2] many consider this first introduction of intradiscal laser technology a pioneering achievement.

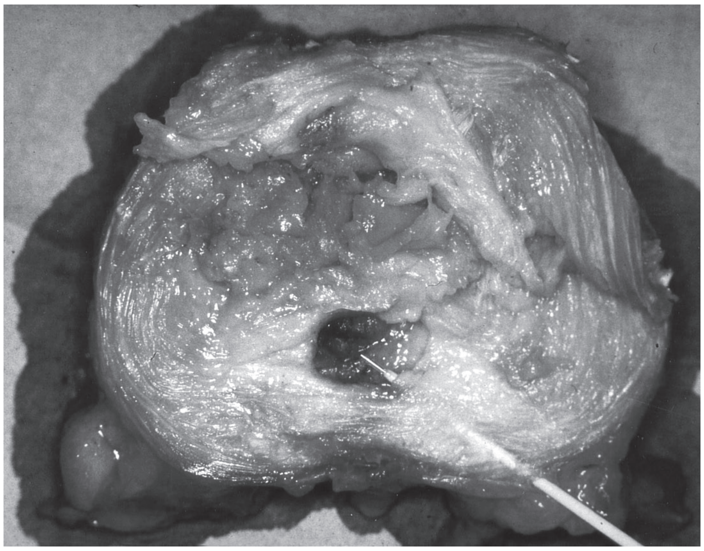

Fig. 29.1 Controlled vaporization of a disc. Note the zone of thermocoagulation surrounding the defect. (Courtesy W. Siebert, M.D.)

PRINCIPLES

Several postulates have been proposed to explain why intranuclear laser decompression can help relieve pain caused by a herniated disc. The first and more apparent reason is the potential beneficial effect of lowering the intradiscal pressure by vaporizing nuclear material. The Nd:YAG 1064 nm irradiation of discal tissue creates a small vaporization defect lined with a carbonized margin (Fig. 29.1) and minimal ablation of disc tissue.[48] Greater ablation is possible with the Nd:YAG laser 1320 nm[4] with pressure a drop of up to 55.6% recorded (Fig. 29.2). This reduction in pressure appears to be independent of age or the degree of disc degeneration.[5] Even though the amount of tissue removed and the ablation defect is less than that achieved with a mechanical discectomy, clinical results are similar using the Nd:YAG laser.

Laser ablation may have other beneficial effects. Some believe that laser provides benefits other than mechanical decompression. One such potential beneficial effect is the shrinkage of collagen fibrils caused by laser-generated heat[6–8] followed by a subsequent reduction of intradiscal volume. We postulated this mechanism after observing sudden shrinking of a resected meniscus irradiated by the Nd:YAG laser 1064nm.[6] Our follow-up studies showed a reduction in disc volume up to 14% in explanted bovine discs, even though comparative studies[6] using the holmium:YAG laser caused 1% or less volume shrinkage. Consistent with our findings regarding disk shrinkage (Fig. 29.3),

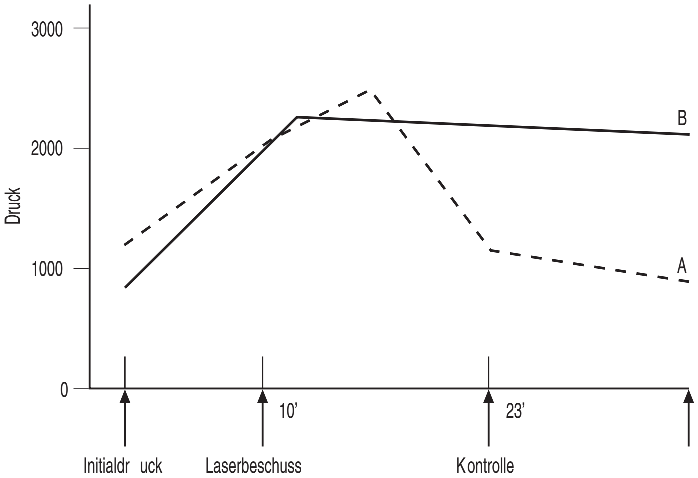

Fig. 29.2 Intradiscal pressure reduction after intradiscal irradiation by Nd:YAG laser (modified from Choy et al.).

Turgut et al.[9] demonstrated water loss, and proteoglycan and collagen changes in animal discs following laser treatment. Kolarik et al.[10] showed size reduction of several millimeters of extruded discs following open surgical Nd:YAG laser disc decompression. As well, Mayer

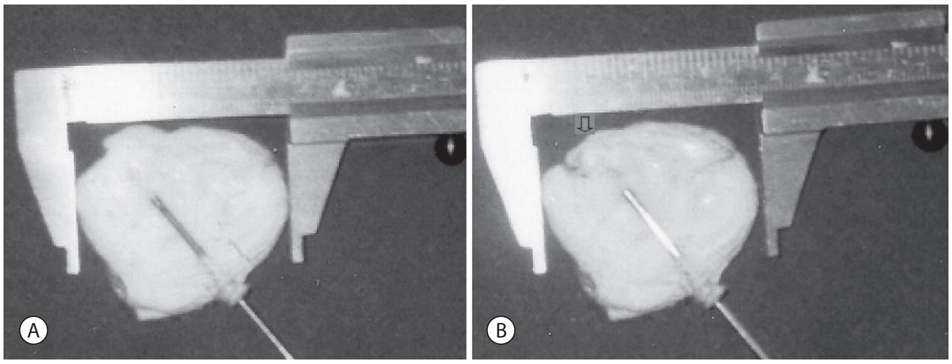

Fig. 29.3 Diameter shrinkage of bovine discs and local shrinking effect (arrow) after intradiscal Nd:YAG 1064 nm shooting up to 750 joule (15 watt, 1 sec).

et al.[11] and Grönemeyer[12] documented disc shrinkage on CT video during endoscopic Nd:YAG laser-assisted percutaneous discectomy.

Reductions in the size of disc protrusions and extrusions have been documented with CT scans performed on the first postoperative day following Nd:YAG:PLDN.[13] Brat[14] similarly documented reduced size of extrusions on postoperative MRI scans. Similar findings were seen on MRI myelograms performed on the first postoperative day[15] where improved CSF flow was demonstrated at the site of the previously constricted dural sac. The authors concluded that the improved CSF flow was evidence of reduced venous dilatation, reduced arteriole compression, and reduced dural sympathetic nerve fiber compression. Because only minimal venous constriction will adversely affect dorsal root neurons[16] and compression often occurs at two adjacent segments,[17] proximal decompression and distal root decompression are recommended.

Contrary to open and most percutaneous surgical disc interventions, the Nd:YAG 1064 nm laser technique may not cause postoperative instability.[18] On the contrary, Wittenberg and Steffen[19] have even reported an increase in translation stability of spinal segments, which they felt was due to a better quality of fibrocatilagenous scar tissue formation.[20] Scar tissue was seen at 6 weeks, but takes a year to mature. They also reported a late shrinking effect of the intervertebral disc without any detectable increased segmental movement.

Finally, another theoretical but unproven potential beneficial side effect of the heat generated during laser ablation is the destruction of nociceptors in the outer anulus, destruction of nociceptors that follow the ingrowth of vascular tissue into radial and concentric anular tears, and the denaturing of inflammatory chemokines.

SAFETY OF USE

Siebert[21] in the lumbar spine and Schmolke et al.[22] in the cervical spine have provided safety data for a Class 4 laser system. At an irradiation time of one shot per second at 20 watts the laser beam will penetrate to a depth of 6 mm in disc tissue. When the laser beam was not directed at the endplate or within the spinal canal, temperatures above the coagulation threshold of proteins were not reached in either the endplate or the epidural tissue adjacent to the disc. Their findings prompted the recommendation that a posterolateral approach be used to access the dorsolateral third of the lumbar and thoracic disc and an anterior approach involving the ventral third of the cervical disc. Based on the experimental studies, the recommended maximal dose per disc is 1600 joules in the lumbar spine, 10 000 joules in the thoracic spine, and 300–400 joules in the cervical spine.

Pilot studies showed that patients under regional anesthesia and analgesic sedation will empirically tolerate single shots of 15 watts at 1 second intervals in both the lumbar and thoracic spine and in the cervical spine, 20 watts every 0.3 second with a 5 second pause after 5 shots. During the past 15 years, the authors have gradually reduced the lumbar dose to 900–1000 joules without any anecdotal difference in clinical outcome. Although endplate injury has been reported during the use a holmium:YAG laser, we have observed no cases of endplate injury using the Nd:YAG laser 1320 nm. We have, however, seen sporadic edematous lesions in the adjacent vertebrae, but these lesions are often seen after open surgery and are of uncertain clinical significance.

Alternative laser technology

Carbon dioxide lasers have a wavelength that is very effective in shrinking the disc;[10] however, using the 1320 nm wavelength requires higher dosing to cause disc shrinkage similar to the Nd:YAG 1064 nm laser. Such higher doses can cause damage to both endplates in 8% of cases[23] and thus its use in disc decompressions is limited.

The KTP laser is very similar to the Nd:YAG laser in both its mode of action and its effect,[24,25] but basic research is significantly less than for the Nd:YAG 1064 nm laser. This diode laser uses 890–980 nm wavelengths and will shrink an intervertebral disc to the same degree as the Nd:YAG 1064 nm laser. Using a wavelength of 940 nm, we validated the shrinking effect of this laser[26] and also showed that a reduced dose could provide sufficient decompression yet still avoid thermal damage to the endplates.

The holmium:YAG laser with a 2100 nm wavelength may not be suitable as a pulsed laser when used for nonendoscopic intradiscal use.[27] The somewhat larger ablated volume compared to the Nd:YAG 1064 nm laser is less than 10 milligrams,[3] and therefore of dubious clinical importance. Furthermore, there is 10% less disc shrinkage, and the apparent scattering may increase the risk of endplate damage.[28]

INDICATIONS AND PATIENT SELECTION

We define pain by its quality, quantity, topology, and chronology and classify inflammatory discogenic pain as causing pseudoradicular, radicular, medullary, or autonomic symptoms. In addition, pain symptoms may be associated with neurological deficits such as dysesthesias, hypo- or hypersensitization, or even paralysis. The cause of these pain syndromes can be diagnosed by a characteristic history and physical examination substantiated by magnetic resonance imaging (MRI) or computed tomography (CT) evidence of disc bulging, protrusions, extrusions, or sequestrations.[29,30] Abnormal structural findings alone without corresponding symptoms are not, however, a reason for surgical intervention.[31]

Patients who fail 6 weeks of conservative care and continue to have disabling discogenic pain are first offered Nd:YAG:PLDN before an open surgical procedure. Although progressive neurologic deficits, paralysis, conus medullaris, and cauda syndrome require immediate intervention, the severity of pain most often dictates when we determine that surgery will be offered. With the exception of a patient with a hemostatic disorder or untreated infection, there are few contraindications to laser decompression. Because shrinkable collagen fibers are always present in the fibrous ring, even age is not a contraindication. In fact, as long as we clinically believe the patient's axial or extremity pain is due to a disc bulge, protrusion, or extrusion and it is seen on a CT or MRI scan, the patient will be offered laser decompression. In particular, laser decompression is not contraindicated when a disc protrusion is aggravating the pain of spinal instability or is contributing to stenos is.[32] Furthermore, many patients who have unrelieved pain for over 6 weeks will begin to develop somatization symptoms, but unlike other authors[18,33] we believe these symptoms are not a contraindication to surgery. In addition, although many physicians including Siebert[18] and others[14,33,34] prefer restricting percutaneous laser decompression to patients with monoradicular pain, the authors have shown that patients with radicular pain alone or predominately radicular pain account for only 20% of patients presenting with discogenic pain. Consequently, the authors believe that axial pain alone is not a contraindication to the performance of laser disc decompression.[35] Finally, the authors do not routinely use discography to confirm the source of pain,[36] but will use discography to help position the cannula during the operation.

In practice, the majority of patients who are offered a percutaneous laser decompression have radicular pain associated with a disc bulge, protrusion, or contained and noncontained extrusions. When selection is limited to patients with radicular pain, patients who will eventually require an open procedure may be less than 10%[35,37] and more than 90% would choose the procedure again for a recurrence in pain (Fig. 29.4). In a consecutive prospective series, 85% of the operated patients had either protrusions or contained extrusions and 15% had noncontained extrusions with either caudal or cranial buttonhole dislocations. The failure rate was 3% in the protrusion-contained extrusion group and even though the failure rate in the noncontained extrusions was 20%, open surgery was avoided in 4 of the 5 cases. Although most surgeons rarely operate on sequestered fragments that are free-floating in the epidural space, many sequestered fragments remain within the protrusion or trapped in the fibrous ring.[38] Furthermore, when there is both a free-floating epidural sequestered fragment and a foraminal disc protrusion, decompression of the protrusion alone may provide enough radicular pain relief such that the patients are satisfied. In the authors' series of 3970 lumbar Nd:YAG: PLDN procedures between 1989 and 2002 there were 7 patients with both protrusions and free-floating sequestered fragments. Six of the seven patients were satisfied with their outcome following nuclear decompression alone, and only three had local axial pain. Two patients with dorsiflexor foot weakness had full recovery.

Finally, most consider cauda equina syndrome as a contraindication for percutaneous disc decompression.[18,39] The authors have, however, successfully performed Nd:YAG:PLDN on 31 cases of cauda equina syndrome. Moreover, in only one case of a recurrent herniation with a free-floating sequestered fragment was open surgery necessary.[40] While this chapter has emphasized lumbar disc disorders, it should be understood that laser decompression may also be considered for

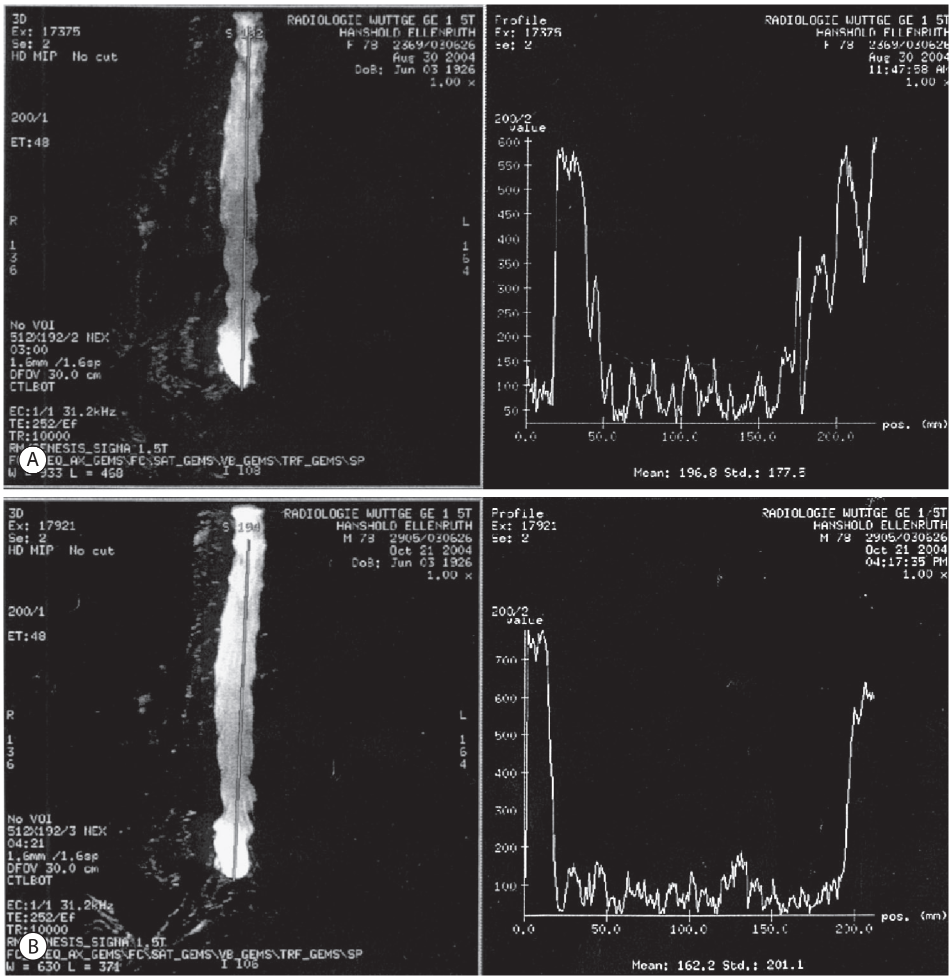

Fig. 29.4 (A) Pre- and (B) postoperative MRI myelogram with evidence of improved dural sac contours and cerebrospinal fluid flow.

symptomatic cord compression in the cervical and thoracic spine when the compression is due to a herniated disc.[41]

TECHNIQUE

In the lumbar and thoracic spine, the patient is positioned in the lateral decubitus position with the painful side up, and a posterolateral approach is used. In the cervical spine, the patient's neck is placed in hyperextension and access is made on the right side between the vessels and the trachea. Local anesthetic is infiltrated in the skin and subcutaneous muscles, and analgesic sedation is given by the anesthetist. Direct and continuous fluoroscopic visualization using intermittent anteroposterior (AP) and lateral projections is used during needle insertions. Because the 400–600 µ bare fiber of the YAG laser extends 2 mm beyond the cannula tip and penetrates to a depth of 6 mm, accurate and specific placement within the disc is important. Although rarely needed, puncture laser osteotomy[42] through the ileum, edge of the vertebral body, osteophyte, or superior articular process will facilitate access to the intervertebral disc. On a rare occasion, transdural puncture will be needed to access the L5–S1 disc.

Technical procedure for nonendoscopic percutaneous laser disc decompression and nucleotomy

Cervical

1. The patient is placed in a prone position with the shoulders supported in order to bring the midcervical spine into the extended position. An anesthetist administers conscious sedation to a level that the patient is comfortable but can communicate with the surgeon.
2. Using continuous fluoroscopic visualization, 10 cc of 1% mepivacaine is infiltrated into the skin and subcutaneous tissue between the carotid artery and the trachea to the depth of the intervertebral disc. Occasionally, a Horner's syndrome will occur.
3. Using a lateral fluoroscopic projection, the appropriate cervical level is identified.
4. The endplates of the desired intervertebral disc are brought into a parallel view by tilting the fluoroscopy tube in a cephalad–caudad direction.
5. Using direct fluoroscopic imaging and while the index finger displaces the trachea medially and the carotid artery laterally, a 1.8 mm external diameter needle is directed into the ventral lateral one-third of the disc and directed towards and parallel to the superior endplate. The final needle position should be approximately 2 mm from the center of the disc. Manual depression of the shoulders may be necessary to visualize the C6–7 or C7–T1 interspace.
6. The needle is manually fixated and the stylet is exchanged for the laser cable which will have the bare laser fibers extending 2 mm beyond the needle tip.
7. Deliver 60 laser shots of 0.3 seconds each, 20 watts in series of five at 5-second intervals. Between intervals allow the irradiated area to cool. Permanent images are recorded to document needle position.
8. While delivering each series continuously check for motor stimulation in upper and lower extremities and maintain verbal contact with the patient so that he or she will report sensations or pain in the extremities
9. Before the needle is removed, the disc the disc is irrigated. Digital compression is applied to the puncture site and a bandage applied.
10. Dressings are next applied and the patient is fitted with a soft neck brace.
11. A Philadelphia collar brace is worn for 6 weeks postprocedure, and NSAIDs are given to control pain.

Thoracic

1. The patient is in lateral decubitus position on operating table with the painful side facing upwards.
2. Local anesthetic infiltration of skin, subcutaneous tissue, paravertebral muscles and the small vertebral joints in the affected segment or in several levels are injected with 30–50 mL mepivacaine 0.5%.
3. In addition to local anesthetic infiltration, sedation by an anesthetist is used to eliminate acute pain during the puncture procedure.
4. Adjustment of the c-arm allows for progressive cephalad counting of vertebrae from L5 allows one to determine the segment to be treated.
5. In the anterolateral projection, a 1.8 mm needle is inserted 6–8 cm paravertebrally on the affected side under intermittent c-arm imaging towards the affected intervertebral disc.
6. After advancing past the costal head under continuous c-arm imaging the intervertebral intradiscal space is reached at an angled position of about 45°.
7. Following puncture, an AP image of the needle penetrating the middle third is taken.
8. Exchange the stylet for the clamping device with the bare fiber extending 2 mm beyond the needle tip. Irradiation with max 1 shot per second, 15 watts per shot up to 900–1000 joules.
9. Continuously check for lower extremity pain or muscle contraction during the administration of laser.
10. Interactive verbal contact with the patient regarding pain is a requirement. If pain is described, pause for up to 5 seconds or reduce the irradiation time while increasing the number of shots to reach the total number of joules.
11. Remove the needle and apply a bandage.
12. Patient should now be placed in the supine position. Monitoring of peripheral neurological findings is conducted.
13. A fluoroscopic view of the thorax is taken to rule out pneumothorax. After 4 hours, a chest X-ray is performed.
14. When analgesic sedation subsides, mobilization with a bridging brace with raised thoracic support pad is made after a plaster cast.

Lumbar

1. The patient is in lateral decubitus position on the operating table with the symptomatic side facing upward with hips and knees slightly flexed.
2. The skin, subcutaneous paravertebral muscles, and dorsal rami of the vertebral nerve are infiltrated with 50–70mL of mepivacaine 0.5% depending on the number of segments involved.
3. Adjust the c-arm to enable the 1.8 mm special needle to be inserted while using an oblique view onto the relevant vertebral intradiscal space followed by posterolateral insertion 6–8 cm laterally to the spinous processes into the disc under continuous c-arm control. An AP view is used to determine whether the needle tip is in the center of the disc.
4. Replace the stylet with the bare fiber marking and clamping device. The bare fiber will extend 2 mm beyond the needle tip, which determines the irradiation zone in the disc.
5. It is not uncommon to encounter difficulty when treating an L5–S1 disc herniation due to a high iliac crest and/or pronounced

sacral inclination. Nevertheless, we can perform this procedure almost exclusively with the semirigid 1.8 mm needle and the stylet without injuring the L5 nerve root. A curved needle has not been used so far by us.

6. Using a conventional approach, one should attempt to position the needle in the posterior third of the intervertebral disc. Using a straight laser application, the nonparallel action of the laser beam has not resulted in any serious consequences our experience.
7. If insertion into the L5–S1 intervertebral space is unsuccessful, puncture laser osteotomy can be performed after deep analgesic sedation. A total application is made of up to 300 joules, one shot per second, 15 watts while exerting mechanical pressure on the needle.
8. Following correct placement of the needle, replace the stylet with the bare fiber.
9. Following application of a series of laser shots with a maximum of 1 second and 15 watts, the needle length is changed on reaching about 750 joules by withdrawing it about 2 mm. This is done under continuous c-arm control, again with verification of proper needle placement.
10. During the procedure, the motor response in the foot and perioperative pain are constantly monitored. If the patient expresses pain, we briefly pause the laser shot application for up to 5 seconds.
11. It is usually possible to puncture 2–3 intervertebral discs from a single access site. For this purpose, the needle tip must be shifted subcutaneously to the respective segment under continuous radiographic guidance.
12. During irradiation, the motor and pain response are checked at regular intervals at a total dose of 900–1000 joules. After the needle is removed, a bandage is applied.
13. Patient should be placed supine until the analgesic sedation subsides. Then the lower extremities are repositioned such that there is 90° hip and 90° knee flexion.
14. The patient is fitted on the same day with a brace prepared from a plaster cast impression. The brace is to be worn daily for 6 weeks. Physical therapy is used only for peripheral paralysis during this interval.

CLINICAL EXPERIENCE

A multicenter prospective study has been conducted. There were a total of 4977 patients, including 316 with cervical and 38 thoracic intervertebral discogenic pain syndromes treated between Nov 23, 1989, and Jan 12, 1999, with by laser. Among the parameters recorded were pain symptomatology, clinical findings, neurological findings, image-based diagnosis and, increasingly, with the computerized spine motion test, with integrated dorsal muscle EMG. Patients with prior intervertebral disc surgery were also enrolled from the outset.[43] The proportion of these patients remained unchanged at 20% over the years. Based on many years' experience with open intervertebral disc and spinal surgery, the polysegmental use of nonendoscopic percutaneous laser disc decompression and nucleotomy with the Nd:YAG laser 1064 nm was introduced.[41]

Ninety percent of patients were followed up at 6 weeks, while the remaining 10% were questioned by telephone interview. This scheduled survey period of 6 weeks was considered the optimal timeframe[44] as it allowed for scar formation of lacerated intervertebral discs.[8]

The results have remained consistently good over the years. Subjective outcome is positive in 80% of lumbar spine cases, 86.5% for cervical spine cases, and 90% for thoracic spine. Visual analogue pain ratings demonstrates a decrease of 80% ($p<0.01$). Objectively, a 90% improvement in lumbar spine patients was observed, as evidenced by the change in the straight leg raising test from the first postoperative day onward. This remains an impressive testimony to the success of intradiscal laser treatments ($p < 0.01$). These findings have been confirmed in follow-up examinations at up to 4 years. More recently, these findings have been demonstrated in up to 8 years' follow-up.[45] Regression of paralysis in all spinal regions was noted to be over 90%. Computerized measurements of spinal mobility have also revealed marked improvement.[35]

COMPLICATIONS

The complication rate is an important criterion for the choice of spinal intervention. Therefore, complications need to be discussed. We will disclose our 15 years of experience with the Nd:YAG:PLDN 1064 nm combined with findings in the literature.[46]

Technical problems

Due to technical problems with the laser tool, one cervical and one lumbar intervention had to be repeated the following day. In another case, the intervention was aborted as fluoroscopy failed during a lumbar intervention. In total, the error quota resulting from technical failure of the laser and X-ray machines was 0.4%. For the lumbar spine, the quotient is 0.1%, while for the cervical spine it was 0.3%. Thoracic interventions thus far have proceeded without complications. Besides the somewhat unpleasant feeling of a repeated intervention, patients did not experience adverse consequences. A needle break has been described following the use of a catheter. However, despite the broken needlepoint remaining in the fatty tissue, no negative effects were reported. Lastly, a single incident of a broken laser fiber point has also been documented.

Problems following the puncture of the discal region

Due to severe cervical spondylosis in the adjacent disc, two of 800 cervical discs were not punctured. In one case, a laser osteotomy was necessary to obtain access. Injuries to the vertebral arteries, trachea, and esophagus did not occur. However, cases of trachea and esophagus injuries have been published, though the incidence is rare. In comparison to open anterior surgical approaches, the risk is significantly smaller. With percutaneous laser interventions, vascular injuries are rare, while damages to the esophagus have been recorded between 0.03% and 0.07%. Pneumothoraces have been reported, but no serious long-term sequelae have been reported. Due to an unsuccessful T5–6 disc puncture, one patient was not laser treated. No puncture-related complications occurred.

In the lumbar spine region, five cases resulted in a prevertebral needle placement. No adverse consequences resulted from this complication. In over 8000 punctured discs, this equates to a complication rate of 0.075%. If access needs to be obtained in the pathological segment, laser osteotomy may be necessary in 0.25% of the cases. Bone injuries did not occur and never negatively influenced the results. When the L5–S1 disc was inaccessible from a posterolateral approach, three cases were performed using a transdural puncture without complications. No nerve root lesions were reported using this technique. Nerve root injury rate of more than 0.46% has been reported with percutaneous nucleotomy (PLD), percutaneous endoscopic discectomy (PED), percutaneous endoscopic laser discectomy (PELD), automated percutaneous lumbar discectomy (APLD), and percutaneous fenestration (PF). The diameter of these aforementioned puncture instruments utilized is significantly larger than the diameter of the puncture tube used for the PLDN (18 gauge to 2 mm exterior diameter). Retroperitoneal vessel damage from Nd:YAG laser was 3%. In 0.15% of the cases, damage to the transverse process was described. In comparison to an open microscopic nucleotomy, nerve root damage occurs in up to 8% while the rate of nerve root injury with the Nd:YAG:PLDN is estimated to be significantly lower.

Hematoma

In the cervical region, three incidents of episternal hematoma were observed without long-term consequences. A frequency of up to 11% has been reported in open procedures. With repeated puncture attempts in the lumbar spine, a large hematoma was observed. In 1.7% of patients, a psoas hematoma developed after APLD and PF interventions. Unlike open procedures that are fatal in up to 1% of cases, these interventions do not affect the spinal canal, and no fatalities occurred.

Intra-abdominal injuries

The most serious complication was a perforation of the ileum. Though the patient was initially free of complaints, he suffered the symptoms of an acute abdomen 2 days after the operation. Subsequently, he required a laparotomy with resection of the small bowel. Histologically, a laser beam-related defect was identified in the small intestine. We suspect the bare fiber penetrated the abdominal cavity where the marking sticker dissolved. It became evident that this resulted in a lesion of the peritoneal lining of the small intestine. As no retroperitoneal signs were noted postprocedure, it is improbably that the laser beam itself penetrated the peritoneal cavity. In comparison to microsurgical discectomies, the incidence of abdominal injuries, including vessels and the ureter, is 1 in 3000. This case has never been reported in any other study, and is clearly the exception. Thus, the statistical frequency of this complication is similar to that of other microsurgical discectomies. There are reported injuries to the sigmoid colon following open L4–5 microdiscectomies. These cases have resulted in a discitis. Ten cases of injuries to the intestine during conventional discectomies have been described. Injuries to the ileum during open operations usually occur when treating the L4–5 segment.

Vasovagal reactions

Only three vasovagal reactions during procedures of the cervical spine have been documented. In all cases, the intervention was technically successful. Besides the effect of the local anesthetic, the cause of this could also be irritation of the carotid sinus during the puncture of the discal region. In cases of cervical discographies, this pathomechanism has resulted in cases of death. In the lumbar spine, one patient's intervention had to be aborted after 300 joule. Nonetheless, the clinical result was very good.

Infections

An intradiscal abscess formation was observed after a lumbar percutaneous laser disc decompression and nucleotomy procedure. The open re-operation was successful in resolving the abscess. Although another case was clinically suspected to be a discitis, no bacterial infection could be verified. Our incidence of infection was 0.08%. Based on numerous reports totaling 8000 completed cases, the infection rate is estimated to be 0.1%. In open discotomies, the rate of infection has been reported to be between 0.2% and 8.5%. In a multicenter study, intradiscal operation procedures were evaluated. The incidence of spondylitis was reported to be 0.3–1.5%.

No infections occurred in the thoracic region. A *Staphylococcus albus* infection of the cervical spine resulted in the paresis of the arm, and required open surgery. There was complete resolution of the paresis. In another instance, an *S. aureus* intradiscal abscess led to quadriplegia. Anterior fusion and laminectomy resulted in almost complete retrogression of the quadriplegia. After 356 completed cervical cases, the rate of infection in cervical laser decompression is 0.5%. This infection rate is still significantly lower than in both anterior (2%) and posterior (1.4–2%) open approaches. One case of a deep cervical soft tissue infections with the Nd:YAG:PLDN procedure was described. In contrast, 0.1–0.7% of soft tissue infections occur with anterior-approach operations on the cervical intervertebral disc. These infection rate statistics prompted prophylactic antibiotic dosing. Following a case of *S. aureus* sepsis, all patients received a preoperative 1-day dose of antibiotics. Since initiating this prophylaxis, no further infections have occurred.

Thromboembolic complications

Three cases of thromboembolic complications following a lumbar procedure will be discussed. In one case, a progressive peroneal palsy developed after a deep vein thrombosis. The patient underwent conservative treatment for several weeks. Both the pain syndrome and paresis were successfully treated, though the PLDN intervention resulted in a pulmonary embolism 1 week later. In a second case of a large disc extrusion at L5–S1, a nonlethal pulmonary embolism occurred 6 weeks after intervention. In the last case of a successful multisegmental decompression for severe central canal stenosis resulting in knee extension weakness, footdrop, and plantarflexion weakness, a deep vein thrombosis occurred in the lower leg. It is estimated that in comparison to open operation procedures, thromboembolic complications are exceptionally rare with percutaneous laser decompression. By comparison, thromboembolic events occur in 5.6% of open cervical spine cases and in 26.5% of lumbar spine cases, especially when general heparinization was not utilized. The patients undergoing laser decompression can immediately be mobilized on the day of surgery. This greatly reduced the risk of thromboembolic complications.

Neurological complications

In the cervical region, neurological deficits occurred after the two infections discussed previously. This corresponds to a rate of 0.5%. Both cases resolved with appropriate treatment and therapy. The rate of neurologic injuries is significantly lower than in open interventions. No neurological deteriorations occurred during thoracic interventions.

In the region of the lumbar spine, four cases of footdrop were recorded. In one case, a footdrop developed from the start. The cause of this has not been identified. When the L5–S1 disc was punctured, a hematoma or thermal damage could have occurred when the cannula was placed near the roots. Two other instances of footdrop resolved after conservative therapy. In one of these cases with contained disc extrusions at two levels, repeating the laser decompression did not result in the retrogression of the footdrop. In the other case, resolution of the dorsiflexion weakness occurred after an open intervention in one female patient. There were no cases of plantarflexion weakness postoperatively. Temporary L3 myotomal weakness was seen in six cases after polysegmental procedures. In all cases, the weakness vanished within 6 months. Two cauda equina syndromes were observed. In one of these cases, the patient's symptoms resolved after removal of an intradiscal abscess. In the other cauda equina case, a 56-year-old Re-PLDN patient developed incontinence after a multisegmental decompression. This could not be cured, and she resigned to self-catheterization. In the first case, an epidural abscess was found to be the culprit. However, no cause could be found. Despite the fact that the conus medullaris and cauda equina syndrome are quite rare, the patient should be appropriately informed of the potential risks involved in this intervention.

In comparison to other percutaneous operation procedures, nerve injuries were described in five of 3194 patients. Neurologic injuries have been reported after chemonucleolysis, including paraplegia, conus medullaris, and cauda equina syndrome at a rate of 0.06%. In open procedures of the lumbar spine, different rates of neurological deficits have been described. It is important to recognize that conus medullaris and cauda equina syndromes, paraplegia, and other severe complications can occur.

Horner's syndrome was not an uncommon occurrence following cervical procedures. A slow improvement of Horner's symptoms occurred after the regional local anesthetic wore off. In one case of a lumbar PLDN at L5–S1, a sympathectomy was noted with increased warmth in the ipsilateral lower extremity. This required 6 months to resolve. In rare cases, the Nd:YAG:PLDN left a neuropathic pain in the region of the knee, the lower leg, and the foot without a radicular component despite the resolution of the positive straight leg raise test. These exceptionally unpleasant sensations usually fade away after 6–12 weeks. An intensive pain therapy program is required when these occur. The cause has not been identified with certainty. Reinnervation pain after long-standing or extensive nerve root damage could possibility be a cause.

Stability damage, damages of the endplates

Thus far, no particular reactions of the endplates have been observed after the utilization of the Nd:YAG:PLDN laser with a wavelength of 1064 nm. Edema in the bordering vertebral bodies was rarely seen, unlike open nucleotomy cases.

DISCUSSION

It is believed that the Nd:YAG laser 1064 nm exhibits two mechanisms of action for eliminating discal sources of pain and weakness.

One is an effect of the kind observed following open intraspinal decompression; mechanical relief of the compressed intraspinal structures such as the venous plexus, spinal arteries, radicular arteries, and neuronal structures such as the nerve root and long tracts. This mechanism of action is based on the combination of intradiscal pressure reduction by vaporization and the shrinking phenomenon with maximal pressure relief in the spinal canal. Relieving venous congestion is of paramount importance in this respect, since only slight increases cause changes in dorsal spinal ganglion synapses.[16] Multisegmental decompression is preferred by the authors to reduce venous stasis. This has been substantiated by the studies of Porter and Warth[17] on the significance of two-level pathology.

The second mechanism of action of the Nd:YAG laser is the destruction of the nociceptors in the posterior fibrous ring for pain relief. Equally as important is the destruction of the budding nerve fibers during neovascularization of the intervertebral disc tissue. The denaturation of pain-activating kinines from the torn intervertebral tissue is a factor that should not be underestimated. The experimental principles described in vitro, in vivo, and in clinical research now leave no doubt as to the efficacy of the Nd:YAG laser 1064 nm on the tissue of the intervertebral disc and thus on pathological manifestations in the form of clinical syndromes, despite a very mixed database. This confusion is due to incorrect quotations,[39] combining results obtained with different types of lasers,[47] and even incorrect scientific statements.[21]

It has been repeatedly asserted that there are psychological effects resulting from laser application that accounts for positive results. To date, no literature has substantiated this concept. Others question whether the procedure is genuinely effective for the patient or merely a 'fun' activity,[11] placebo, or even nonsense. We believe that the clinical results of the megastudy and the evaluation of the meta-analysis impressively refute those claims.[48]

LASER SELECTION

The use of lasers naturally requires the necessary knowledge of laser physics and the ability to select an appropriate laser. Positive results can only be achieved if the right laser is used with a suitable wavelength. Experimental and clinical results have shown that the ideal choice is the Nd:YAG laser 1064 nm. The Nd:YAG laser1320 nm also provides good results, but requires at least a threefold higher dose. Unfortunately, this higher dose can result in damage to the adjacent vertebrae. The holmium:YAG laser is less suitable for nonendoscopic operations, i.e. those performed only through percutaneous needle puncture.[49] Based on our experimental studies and clinical experience, this technique should only be used in open or endoscopic intervertebral disc operations in an assistive mode and under visual control.[27]

The recently developed diode laser with wavelengths of around 940 nm (910–980 nm) has the greatest thermal effect with a very good shrinking mechanism. This has been shown by experimental research conducted by my own research group. In a prospective, randomized, single-blind clinical study, it provided the same results as the Nd:YAG laser 1064 nm without an increase in complications.[26] Regrettably, cases in which much too high doses were used have also been reported, resulting in severe damage to the adjacent vertebrae. The same applies for the KTP laser which, when the correct fiber tip is chosen for straight shooting, provides good results without damaging the adjacent vertebrae.

Nonendoscopic laser types used:

KTP 532 side firing
Diode 890–980 straight firing
Nd:YAG 1064 straight firing
Nd:YAG 1320 straight firing
Ho:YAG 2100 side firing
Ho:YAG 2100 straight firing

SUMMARY

In a large number of patients, discogenic vertebrogenic pain syndromes can be eliminated or reduced to a tolerable level. The success rate of patient satisfaction is 80% for the lumbar spine, 86.5% for the cervical spine, and 95% for the thoracic spine. With a complication rate to date of 0.66 % as demonstrated by meta-analyses, the procedure appears to be safe.

AU: This is 90% in the last paragraph of the section on Clinical Experience. Which is correct?

Because of its absorption spectrum, the Nd:YAG laser 1064 nm has been shown in experimental studies to offer the best preconditions for inducing a radical drop in pressure by vaporizing disc tissue. The sudden drop in pressure in the spinal canal due to the shrinking effect associated with the thermal action, accompanied by shortening of the collagen fibrils in the intervertebral disc structure, is to be regarded as an even more important process. Additional effects include the increased stability of the moving segment and the destruction of nociceptors and nerve fibers in the posterior fibrous ring as well as the vascularized intervertebral disc in the degeneration process. Also not to be neglected is the denaturing of pain-inducing intervertebral disc-generated kinines.

Since exact studies on the penetration depth of the Nd:YAG 1064 nm laser beam and heat convection have not produced any evidence of damage when using the correct dose, the Nd:YAG laser 1064 is currently the laser (1, 3, 6, 8, 18, 53, 55, 63) of choice for intradiscal intervertebral disc decompression and nucleotomy.[45,47,50–55]

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