Acute Effects of Nd: YAG Laser on Intervertebral Disc and Endplate: An Experimental Study Using a Cadaveric Sheep Model

Nd: YAG Lazerin İntervertebral Disk ve End-Plate Üzerindeki Akut Etkileri: Bir Koyun Kadavrası Modeli Üzerinde Deneysel Bir Çalışma

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Özet: Nükleus pulpozus herniasyonu nöroşirürjide en sık rastlanan sorunlardan birisidir ve "perkütan lazer nükleotomi" de intervertebral disk herniasyonunda yeni bir sağaltım yöntemidir. Bugüne dek kimi klinik ve deneysel çalışmalarda lazer enerjisinin disk dokusu ya da kıkırdak "end-plateler" üzerindeki etkisi bildirilmiştir. Bu çalışmaların aksine lomber diskleri daha geniş olan ve dejenere insan disklerinde olduğu gibi, düşük su içeriği olan lomber disklerin kullanıldığı bir koyun kadavrası modelinde, hastalarımız için nöral ya da kemik hasarına yol açmayacak en uygun lazer ışınlama koşullarını bulmaya çalıştık. Morfolojik değişikliklerin düzeyini değerlendirmek amacıyla farklı lazer jüllerini izleyen makroskopik ve histolojik bulguları araştırdık. Yeterli bir disk buharlaşması için 1000 ile 1500 jül arasında lazer uygulanması gerektiğini saptadık. Disk dışı doku yıkımının ilk kez "end-plateler"de 400 jülde izlendiği ve laser probunun ucunun yeri değiştirilmeden yeterli disk dekompresyonu sağlamaya çalışıldığında da dura ve kemiğin ısı etkileşimine uğradığı gözlendi. Bu nedenle, disk aralığının değişik bölümlerinin düşük lazer jülleri ile buharlaştırma gerektiği sonucuna ulaşıldı.

Anahtar Sözcükler: Lazer, lomber disk hernisi, perkütan nükleotomi.

***Summary:** In neurosurgery, herniated nucleus pulposus is one of the most common problems and enthusiastic reports about percutaneous intradiscal laser nucleotomy have been encouraging to neurosurgeons treating patients with intervertebral disc herniation. To date, the effect of laser energy on either the disc tissue or the catilagineous end-plates has been addressed in some clinical and experimental studies. Contrary to those reports, we tried to derive the optimum laser irradiation conditions for the patients without leading to neural or bony damage in a cadaveric sheep model, in which lumbar discs were relatively large and had low water content as in the degenerated human discs. The macroscopic and histological features following different laser joules were undertaken to evaluate the extent of morphological changes. We observed that 1000 to 1500 joules of laser should be applied in order to get a satisfactory disc vaporization. Since the extradiscal tissue damage was first witnessed on the end-plates at 400 joules, the dura and bone were destructed by the heat effect when satisfactory disc decompression was tried to be achieved without changing the location of the laser probe. Therefore, different parts of the disc space should be vaporized with low joules of laser irradiation.*

***Key Words:** Laser, lumbar disc hernia, percutaneous nucleotomy.*

Intervertebral disc herniation is an important health problem from both the social and economic aspects. It is estimated that about 60 to 80% of the people had experienced an acute attact of back pain at sometime in their life (1). Prevention of morbidity and mortality, complete relief of pain, and having a rapid healing process are the main priciples of solving this problem (2). In the early 1980s, percutaneous chemonucleolysis with chymopapain has been developed as an alternative to conventional surgical methods. But complications, such as anaphylactic shock and paraplegia (3) steered neurosurgeons away from this technique towards automated percutaneous nucleutomy in the late 1980s (4-6). However, in this procedure, the automated nucleotome canula may cause technical problems and tissue damage. Intradiscal laser nucleotomy is a recent percutaneous technique which has the following advantages; output power is controllable, extradiscal tissue damage is minimized, and complications of chemical substances are avoided (3). Clinical studies have also shown that laser surgery decreases morbidity and hospitalization period, and has a success rate of 70 to 75% in disc herniations (7-9). In this invitro study, we tried to determine the acute macroscopic and histological features caused by laser nucleotomy (LN). Since previous studies on normal or degenerated disc material were performed in small-sized animals like rats (2,10,11), we preferred to use the cadaveric sheep lumbar vertebrae. This enabled us to irradiate a disc tissue having lower water content as that of a degenerated disc with the range of joules that are applied to our patients.

Materials and Methods

In our study we investigated the acute macroscopic and histological changes related to laser nucleotomy. For investigating these parameters, 24 different laser irradiation conditions were used. Each condition was performed in 5 different disc spaces. 120 cadaveric sheep vertebral sections with lumbar discs, adjacent vertebral bodies, and intact posterior elements were used during the experiments.

The disc space was entered with a single lumen, 14-gauge needle. After the laser probe had been introduced through it, first the central and then, lateral part of all discs were vaporized as we usually do in our patients. We used a Neodymium-yttrium-aluminum-garnet (Nd:YAG) laser device (wavelength: 1.064 nm, Messerschmitt-Bolkow-Blohm GmbH, Germany) with its bare fiber (outer diameter 1.0 mm).

Laser irradiation was done under the following conditions;

a. Output powers were 5 watts (W), 10 W, or 15 W respectively,

b. Pulse interval at each power level was 1 or 2 seconds (sec.),

c. Number of laser pulses were as follows;

(30+10)=30 pulses in the disc center, 10 pulses laterally near foramen

(60+15)=60 pulses in the disc center, 15 pulses laterally near foramen

(80+20)=80 pulses in the disc center, 20 pulses laterally near foramen

(75+25)=75 pulses in the disc center, 25 pulses laterlly near foramen

All of the specimens were fixed with 10% formalin before photographs of the end-plates and discs of each irradiated disc space were taken. Then the permanent sections were stained with four different dyes (Hematoxylin and Eosin, Van Giesson, Reticulin and Masson Tricrom) for light microscopic observations.

Results

Macroscopic changes: The macroscopic changes of irradiated disc tissues and end-plates occured in proportion to the laser energy used. The margins of the vaporized disc space created by the laser were carbonated near the site where the tip of the probe had been inserted. When the output powers were high, not only the nucleus pulposus, but also the end-plate and anulus adjacent to the foramen were destroyed. The output powers higher than 5 watts, 2 sec., 60+15 pulses (750 joules) led to striking disc tissue destruction. With 10 watts, 1 sec., 80+20 and 75+25 pulses (1000 joules), macroscopically one third, with 15 watts, 1 sec., 80+20 and 75+25 pulss (1500 joules) half (Figure 1), and with 15 watts, 2 sec., over half (Figure 2) of the disc spaces were vaporized. End-plate burn was first witnessed after a laser irradiation of 5 watts, 2 sec., 30+10 pulses (400 joules). A concavity into the end-plate occured with the usage of output powers of 10 watts, 2 sec (>800 joules). The anulus fibrosis began to damaged when 15 watts, 2 sec., 60+15, 80+20, and 75+25 pulses of laser irradiations were employed (Figure 1). The most remarkable changes near the foramens were seen after 15 watts, 2 sec., 80+20 and 75+25 pulses of irradiation. Almost all disc tissue was carbonized and the dura was discolored (Figure 1).

Histological changes: Histological changes in the irradiated disc tissues were investigated under light microscopy using four different dyes. Destruction, scattering, and degeneration of the connective tissue, changes in the number and appearance of the nuclei, and the changes in PLL (posterior longitudinal ligament) and anulus fibrosis were studied at each energy level. Finally three distinct groups were found in which the degree of the changes were in proportion with the amount of laser energy. In the first group, the findings are minor and are witnessed between the laser irradiation condition of 5 W, 1 sec., 30+10 pulses and 5 W, 2 sec., 60+15 pulses (<750 joules). In this group scattering, thinning, homogenization of the connective tissue and decrease in the number and volume of the nuclei (picnosis) were observed (Figure 3). In the second group, moderate changes were seen between the irradiation conditions of 5 W, 2 sec., 80+20 pulses and 15 W, 2 sec., 30+10 pulses (750-1200 joules). In addition to the findings of the first group, microcysts were detected (Figure 4). In the last group with major changes (Figure 5), the above features were more widespread and prominent (>1200 joules). Histological changes induced by laser irradiation included decomposition, homogenization, and denaturation in the cartilagineous matrix, swelling of the nuclei, and cytologic denaturation (at 400 joules). Denaturation (at 750 joules) was also seen in adjacent bone marrow (Figure 6).

Discussion

The intervertebral disc which has an important role in the continuation of biomechanical functions of the spinal column is composed of three anatomical regions; anulus fibrosis, nucleus pulposus, and cartilage end-plate and normal disc tissue is quite a rigid material which is closed to the surrounding structures (12). As a result of disc degeneration related to ageing or disc herniation, water and proteoglycan content of the disc decreases with loss of hydrostatic properties (13, 14). The standard surgical procedure for disc herniation is laminotomy and discectomy. Recently, several percutaneous discectomy methods have been proposed in the treatment of disc herniations (15-17). In contrast to conventional surgical techniques, painful procedures such as incision of the skin, dissection of the muscles and removal of the bone are not performed in percutaneous disc surgery. In 1986, Choy and Ascher applied laser surgery for the first time to the intervertebral disc resulting in coagulation and shrinkage in the size of the disc (18). It is accepted that vaporization created by Nd:YAG laser is primarily due to the heat effect of the laser. As a result, shrinkage occurs in the disc tissue, leading to the formation of vapour, carbon, CO_2 and carbonized tissue fragments and the intradical pressure decreases (19,20). To date, there have been some reports of experiments demonstrating the effects of Nd: YAG laser either in normal or degenerated discs, but all of those studies were performed in small-sized animals (2,10,11). In addition, it is very hard to derive the optimum irradiation conditions for our patients from those studies. Turgut, et al., claimed that laser nucleotomy might be effective in the shrinkage of the discs with normal texture (2). But in cases with degenerated disc herniation, they believe that high joules of laser should be applied in order to vaporize the disc because of its lower water content, and they stated that this would inevitably lead to damage to either the vertebral end-plates and neighboring neural structures (2,21). On the other hand, it is a reality that laser nucleotomy has a success rate of 70 to 75% in a certain group of patients (7-9) and this was attributed to the decrease in the intradiscal pressure with the drop ranging 10% to 69% (21,22). However, the role of thermal changes is less clear. Schoenenberger. et al., showed the well correlation of the macroscopic size of necrosis with the real-time monitored temperature spread by the superconducting, open-configuration magnetic resonance system (23). Some authors have recorded

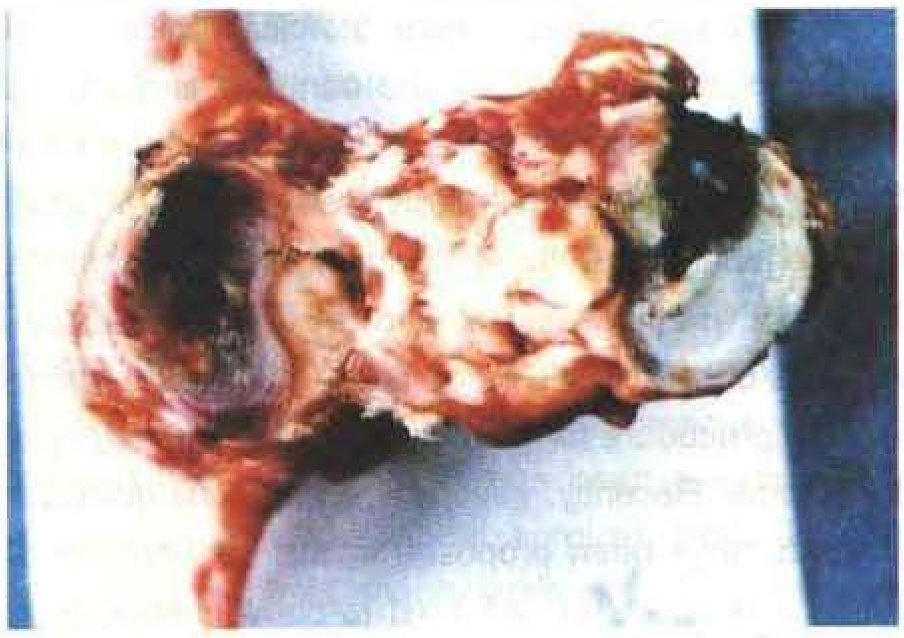

Figure 1. After 15W, 1 sec., 75+25 pulses (1500 joules) of LN, over half of the disc is vaporized, leaving a carbonized surface, macroscopic changes in the posterior longitudinal ligament, end-plate and anulus fibrosis.

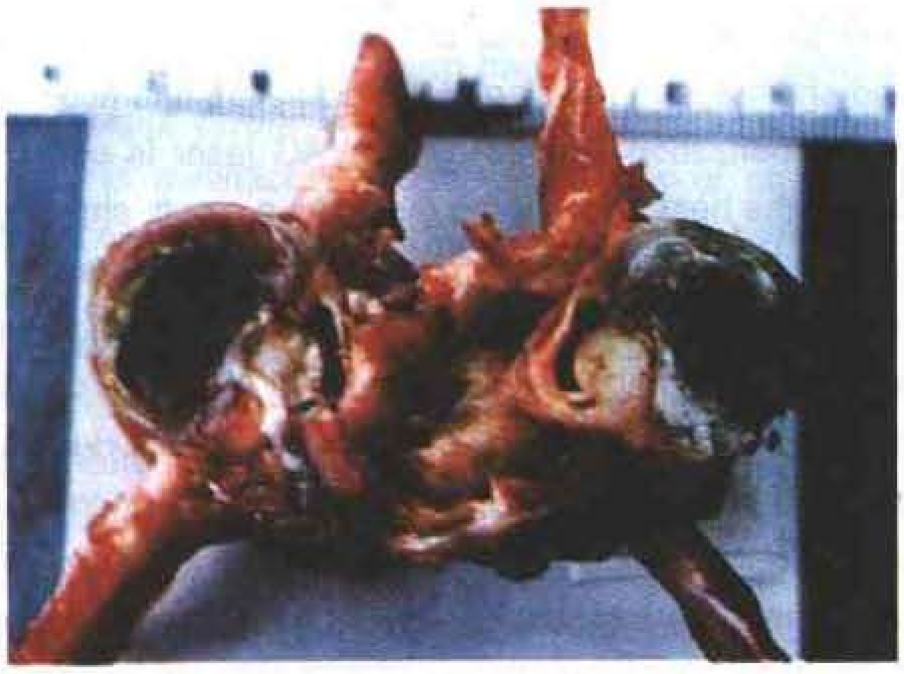

Figure 2. After 15W, 2 sec., 75+25 pulses (3000 joules) of LN: Almost complete disc vaporization with carbonization of the disc and end-plate together. Macroscopic thermal changes in the dura are also seen.

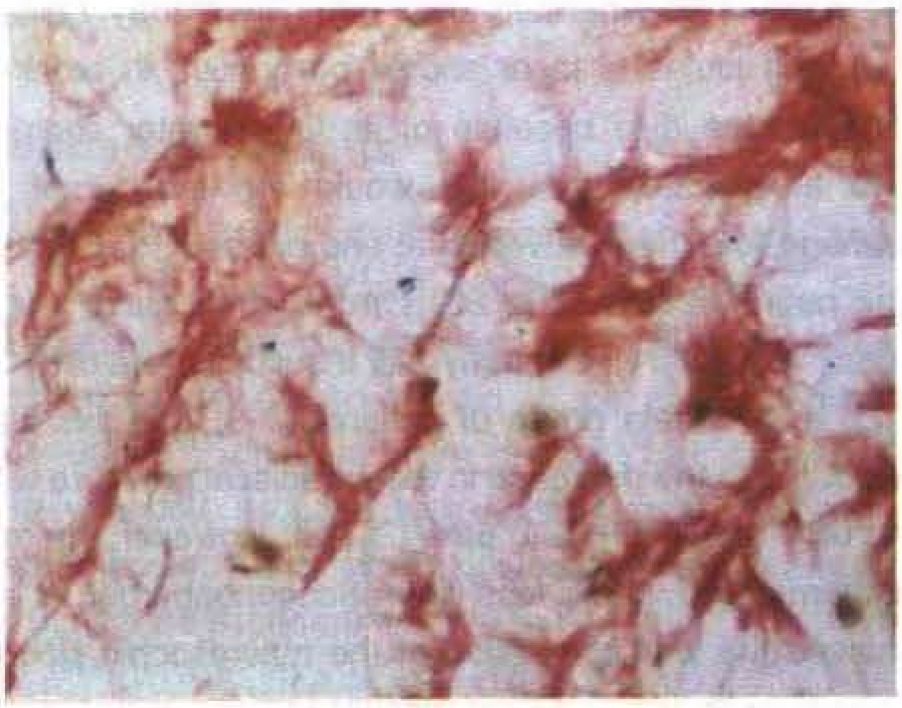

Figure 3. After 5W, 2 sec., 75+25 pulses (1000 joules) of LN, scattering, homogenization and picnosis of connective tissue fibers were observed histology (Van Giesson, 200X).

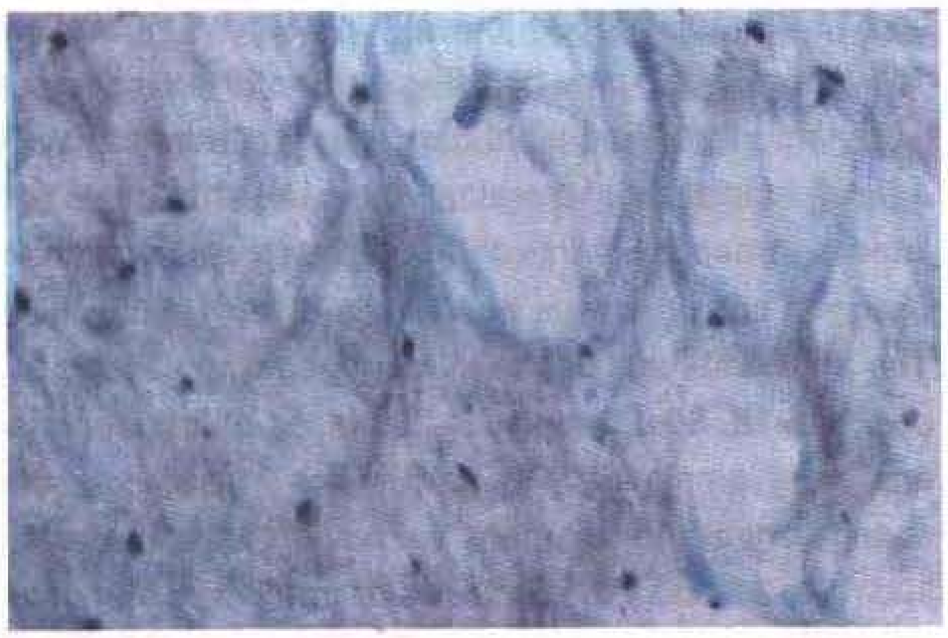

Figure 4. After 10W, 2 sec., 80+20 pulses (2000 joules) of LN, microcysts were detected in addition to the findings of figure 5 (Reticulin, 10X).

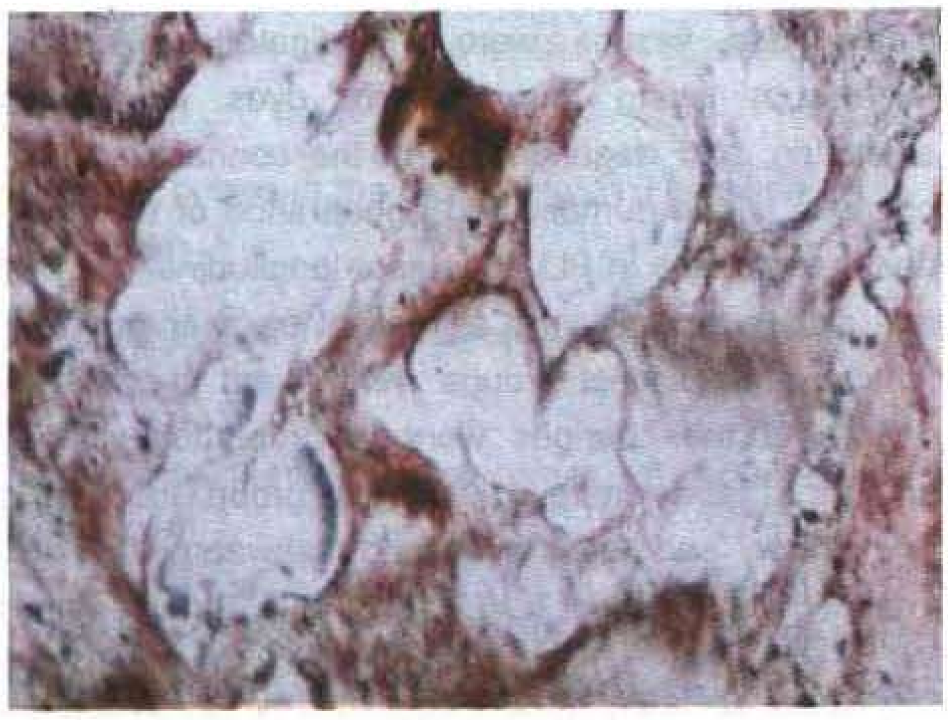

Figure 5. After 15W, 1 sec., 75+25 pulses (1500 joules) of LN, microcysts, homogenization of the connective tissue and picnosis are prominent (Masson Tricrom, 100X).

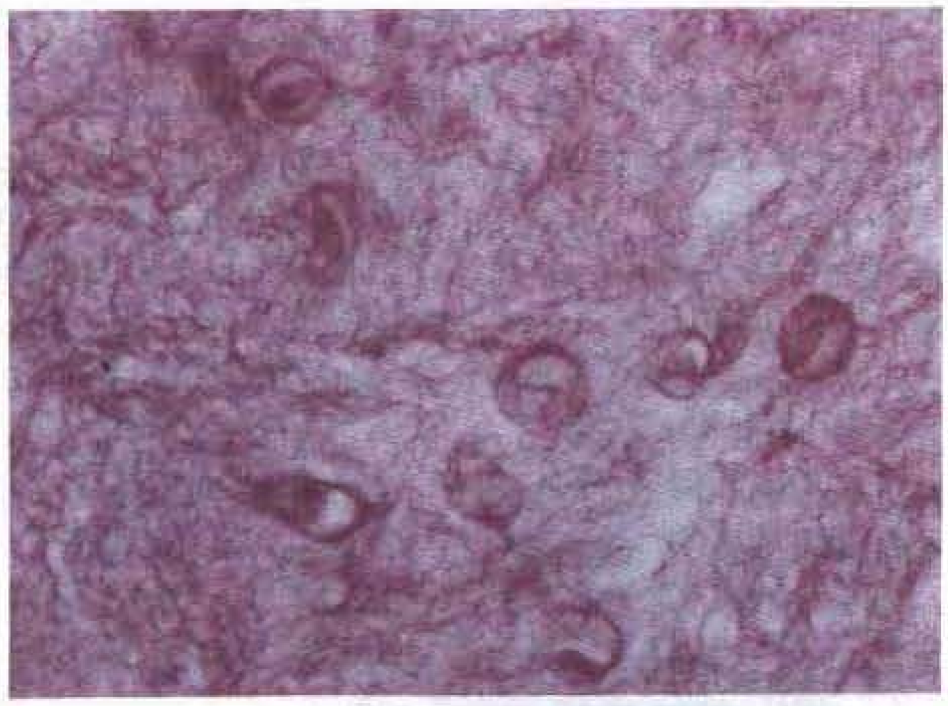

Figure 6. After 15W, 2 sec., 30+10 pulses (1200 joules) of LN homogenization and denaturation of the cartilagineous matrix and swelling of nuclei are observed (H&E, 200X).

high temperatures, close to 40°C at the anulus (24). Our patients also complain from burning sensation and pain during laser applications, but these complaints are temporary and resolve when waited a few minutes. Very rarely, this thermal injury may lead to severe disability as it is in cases with the complex regional pain syndrome Type II with sympathetically maintained pain (25).

The purpose of this study was to find out the optimum laser irradiation condition without leading to thermal damage. Since the cadaveric sheep specimens were used, their relatively larger size and lower water content were suitable for stimulating the conditions as that of cases with degenerated discs. When the tip of the laser probe was kept in the same location (in the center of the disc), the end-plate burn was witnessed after a laser irradiation of 400 joules and a concavitiy into the end-plate occured with the usage of 800 joules of laser. The ablation of the disc tissue with these joules of laser was demonstrated either macroscopically and histologically. But if the procedure was stopped at this point because of the bone destruction, the decompression would be unsatisfactory, since only one third of the disc could be vaporized. Thus, if the position of the tip of the laser probe was not changed with the purpose of more disc vaporization, the increased heat produced by laser energy might cause damage to the neural structures. We achieved a very satisfactory disc vaporization (over half of the disc tissue) when 2000 or higher joules of laser was used in the center of the disc space, but unwillingly, the dura and neural structures were affected by the heat. Recently, the introduction of new laser types has been started with the purpose of decreasing thermal damage and avoiding the prolongation of wound healing (26,27). But, the easiest way to obtain a satisfactory decompression is to change the position of the tip of the laser probe in the disc and to give a pause before beginning a new irradiation period. This will enable us to vaporize the different regions of the disc with low laser energy and prevent us damaging either the bone or neural structures. Although we irradiated only two distinct regions of the disc spaces, this study showed that the number of the irradiated regions could be increased. However, the amount of the low laser energy for any part of the disc tissue may be optimum, only when it is not allowed to exceed 400 joules, especially near the neural foramen.

Acknowlegements

The authors wold like to thank Dr. John Fowler for his help in preparing this manuscript.

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