Nonoperative Treatment of Herniated Lumbar Intervertebral Disc with Radiculopathy

An Outcome Study

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The functional outcome of patients with lumbar herniated nucleus pulposus without significant stenosis was analyzed in a retrospective cohort study. Inclusion criteria were as follows: 1) a chief complaint of leg pain, primarily; 2) a positive straight leg raising (SLR) at less than 60° reproducing the leg pain; 3) a computed tomography (CT) scan demonstrating a herniated nucleus pulposus without significant stenosis by a radiologist's reading, which was also confirmed by the authors; 4) a positive electromyogram (EMG) demonstrating evidence of radiculopathy; and 5) response to a follow-up questionnaire. All patients had undergone an aggressive physical rehabilitation program consisting of back school and stabilization exercise training. Of a total of 347 consecutively identified patients, 64 patients with an average follow-up time of 31.1 months met the inclusion criteria and constituted the study population. They were sent questionnaires that inquired about activity level, pain level, work status, and further medical care. The patients with neurologic loss, extruded discs, and those seeking a second opinion regarding surgery were identified and subgrouped. Results for the total group included 90% good or excellent outcome with a 92% return to work rate. For the subgroups with extruded discs and second opinions, 87% and 83% had good or excellent outcomes, respectively, all (100%) of whom returned to work. Sick leave time for these subgroups was 2.9 months (±1.4 months) and 3.4 months (±1.7 months), respectively. These results compared favorably with previously published surgical studies. Four of six patients who required surgery were found to have stenosis at operation. There was no statistically significant difference in outcome in the patients with neurologic weakness or with extruded discs from the total study population. This study demonstrates that herniated nucleus pulposus of a lumbar intervertebral disc with radiculopathy can be treated very successfully with aggressive nonoperative care. Surgery should be reserved for those patients for whom function cannot be satisfactorily improved by a physical rehabilitation program. Failure to respond to nonoperative care should suggest the presence of stenosis. [Key words: lumbar herniated disc, nonoperative treatment, clinical course]

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LUMBAR INTERVERTEBRAL DISC HERNIATION is a common cause of low-back pain and radiculopathy. Although more than 50 years have passed since Mixter and Barr's initial reports,[24] controversy still exists regarding indications for surgical intervention, and the appropriate surgical procedure of choice. Disc extrusion has been considered a condition best dealt with by surgical intervention,[2,31,32,33] and weakness often is still considered an indication for surgery despite the favorable outcome reported by Weber.[39,40] Consequently, the role of nonoperative management of this clinical condition remains open for debate.

The presence of lateral stenosis as a reason for failed lumbar disc surgery is well described by Burton et al.[3] It is, therefore, apparent that patients having herniated discs with stenosis fall into a separate and distinct clinical subtype from patients having herniated discs without stenosis, and that each possesses different outcomes requiring different therapeutic approaches and surgical decision-making criteria. Previous studies have not distinguished patients with or without stenosis accompanying their herniated intervertebral discs.[2,8,11,16,25,31,32,33,39,40,41]

In addition, there have been studies suggesting that surgically treated patients with herniated discs have had a more favorable outcome in the first year than non-surgically treated patients.[14,39,40]

We undertook the present study in an attempt to determine whether patients with lumbar disc herniation and radiculopathy without stenosis could be treated effectively with aggressive conservative care. Additionally, we wished to determine the recovery time of our patients.

Our study group consisted of patients with seemingly acceptable surgical indications as reported in previous studies. These indications included extruded discs, neurologic weakness, and failure to improve with conservative measures such as bed rest, traction, and therapeutic exercises. Also in the study group were a group of patients who were advised by a surgeon that surgical intervention was absolutely necessary and should not be delayed.

MATERIALS AND METHODS

The available records of patients seen at our spine specialty clinic with a diagnosis of herniated lumbar intervertebral disc between January 1, 1985 and April 1, 1986 were reviewed. Patients who met the following criteria were included in the study group: 1) Those with an available computed tomography (CT) scan and/or magnetic resonance imaging (MRI) data with a radiologic interpretation of "herniated nucleus pulposus." 2) Those with a diagnosis of lumbar radiculopathy based on:

a) A primary complaint of leg pain and a secondary complaint of back pain supported by a similar pattern on a patient-completed pain diagram.

b) A positive electromyogram (EMG) study demonstrating the electrophysiologic presence of lumbar radiculopathy.

c) A positive straight leg raising test reproducing leg pain at less than 60° elevation.

d) An aggressive treatment program, undergone by all patients, which included: back school; exercise training to teach spinal stabilization, ie, dynamic maintenance of postural control, trunk, and general upper and lower body-strengthening exercises; and flexibility exercises. Epidural injections and/or selective nerve root blocks were used when indicated for pain control. The underlying premise of the program was that the patient undergo active, not passive, treatment.

Criteria that excluded patients from the study group were: 1) previous lumbar spine surgery, and 2) the presence of significant stenosis or spondylolisthesis as noted on a CT scan or MRI scanning (significant stenosis, defined as a minimum of a Grade 3 on the Glenn Scale[10]).

All CT and MRI scans were reviewed by the authors for confirmation of diagnostic findings. Patients with contained herniations versus extruded fragments were noted (disc herniation, defined as a focal posterior disc abnormality of at least 5 mm). Data collected from a patient chart review included:

1) the history of the chief complaint of leg and back pain,
2) the patient-completed pain diagram,
3) the duration of the symptoms,
4) a history of request for second opinion regarding surgery,
5) the patient's work status at the time of initial evaluation,
6) physical exam findings of weakness and straight leg raising, and
7) EMG test results.

A standardized questionnaire including questions from the Oswestry Scale,[7] pain self-rating, work status, and self-rating of outcome were mailed to each patient who met the above criteria. Patients were additionally asked if they underwent either subsequent surgical or nonoperative treatment after completing our program. Self-rating criteria were as follows:

1) *Excellent:* Working full-time, performing usual athletic activities;
2) *Good:* Working full-time but limited in performance of athletic activities;
3) *Fair:* Working part-time only, unable to participate in athletic activities;
4) *Poor:* Unable to work and unimproved following treatment.

Out of a total of 347 consecutively identified patient records reviewed, 64 were included in the group to whom questionnaires were mailed. Exclusion criteria included the diagnostic factors mentioned above, and nonavailability of patient CT scans. All questionnaires not returned within 3 weeks from the initial mailing resulted in a repeat mailing with a letter requesting completion. If no response was obtained by the second mailing, follow-up phone calls were made and the questionnaire was completed. A total of 58 questionnaires were returned—a 91% response rate.

Data analysis included calculation of: 1) rates of return to work, 2) average sick-leave time, 3) subsequent surgery due to failure of conservative care, and 4) a self-rating of outcome.

Rates were calculated for the entire study population, a comparison between the worker's compensation patients and private pay patients was made, and contained versus extruded herniations were noted. Separate rates of outcome were determined for the group of patients seeking a second opinion regarding surgery.

RESULTS

Total Study Population

Of 58 patients in the study, there were 36 men and 22 women, with a median age of 35.5 ± 1.2 years. Thirteen (22%) were worker's compensation cases. Weakness (minimum strength loss of one grade on a grading system of 0–5) was noted in 37 (64%). Symptom duration averaged 4.6 ± 0.6 months, with a mean post-care follow-up time of 31.1 ± 1.7 months. Six patients required surgery.

Table 1. Summary of Data

	Percent return to work	*Sick leave (mos)*
Total study population (n = 58)	93	4.6 ± 1.1
Nonoperative treatment subgroups		
Subgroup having extruded discs (n = 13)	100	2.9 ± 1.4
Surgical second opinion subgroup (n = 15)	100	3.4 ± 1.7
Worker's compensation subgroup (n = 11)	86	9 ± 3.3

Nonoperative Treatment Patients

Of a total of 52 nonoperative patients, 50, those with "Good" or "Excellent" outcomes, were considered sucesses (85 ± 5.2%) of the entire study population; 96% of all nonoperative cases). Forty-eight patients returned to work (83 ± 5.2% of the entire study population; 92 ± 3.5% of all nonoperative patients); 85 ± 5% of all of the patients returned to their previous jobs. The average sick-leave time required by patients in this group was 3.8 ± 1.0 months. Twenty-six patients (50 ± 6.9%) reported less than 1 week sick-leave.

The self-rated reports for these patients were *Excellent:* 15 (29 ± 6.3%); *Good:* 35 (67 ± 6.8%); *Fair:* 2 (4 ± 2.7%); and *Poor:* 0 (0%). Both "Fair" scores were worker's compensation cases. Median Oswestry score for the "Good" group was 20; for the "Excellent" group, 16.6; and for the "Fair" group, 32. Therefore, 20 patients who categorized themselves as "Good" by self-report could fall into the "Excellent" group. This would yield 31 "Excellent" results and 14 "Good" ones.

Eleven (86 ± 4.8%) worker's compensation patients returned to work, with an average sick-leave time of 9 ± 3 months.

Nonoperative Treatment Failures

Six patients required subsequent surgery after unsatisfactory improvement with the nonoperative program. Four of these were noted as having significant stenosis at the time of operation. One patient had progressive weakness, and one did not complete the program and, on her own, referred herself to surgery.

Surgical Second Opinion Subgroup

Eighteen (31%) patients were seen for a second opinion regarding surgical intervention. All of these patients had been advised by a surgeon that they needed surgery as soon as possible to avoid long-term complications.

Of these 18, 15 (83 ± 8.9%) were nonoperative treatment successes, three (20 ± 10.3%) scoring "Excellent" on the self-rating reports and 12 (80 ± 10.3%) scoring "Good." All 15 (100%) returned to work (RTW/nonoperative successes), with an average sick-leave time taken of 3.4 ± 1.8 months.

Subgroup Having Extruded Discs

Extruded discs were noted on CT and/or MRI scans in 15 patients (26%). Of these, 11 had weakness. Thirteen (87 ± 8.7%) were nonoperative treatment successes, with an average sick-leave time of 2.0 ± 1.4 months. Nine of 13 reported less than 1 week sick-leave time.

Three of the patients having extruded discs required subsequent surgery. One patient needed surgical intervention because of progressive weakness. Of the other two, one was found at the time of surgery to have significant lateral recess stenosis and the other referred herself to surgery on her own, and did not complete the program.

DISCUSSION

In this investigation, we used a cohort study design to analyze the results of a group of patients treated nonoperatively for lumbar intervertebral disc herniation. Unfortunately, retrospective longitudinal analyses of this type have inherent weaknesses. Inconsistencies in data retrieval from preexistent medical records, as well as the difficulties of locating patients to be included in the study's population can lead to inadvertent patient selection bias. We minimized that problem, however, by using a standardized record-keeping system and by selecting a group of consecutively identified patients who met the study's strict inclusion criteria. Although this approach is not as rigorous as a randomized, controlled evaluation of a treatment method, it does adequately deal with the questions we are asking.

We studied a discrete population treated at one facility and followed it for more than 2 years. The study's subjects were reliably identified as having a lumbar radiculopathy due to intervertebral disc herniation by objective criteria. All patients in the study group had a primary complaint of leg pain, a straight leg raising (SLR) that reproduced this pain at less than 60°, and an EMG that demonstrated electrophysiologic evidence of radiculopathy. The CT scan data was obtained from the medical records and the scans were viewed once again by the authors. Stenosis was graded using the Glenn and Rothman scale[3,10] and had to be at least a Grade 3 to be excluded. Therefore, our study's population had both the clinical symptoms attributable to herniated nucleus pulposus (HNP) and the imaging and electrophysiologic data confirming it.

All patients had failed passive "conservative" management, and were consequently comparable clinically to the patients evaluated in surgical studies of herniated lumbar discs. Additionally, included in the study population can be found a subgroup of patients evaluated for surgical second opinion. This group had been identified for surgical treatment and, in essence, was reassigned to nonoperative intervention. Thus, these patients may serve as their own controls.

The use of questionnaires to obtain follow-up data has a number of pitfalls.[4,5,7,17,19] These include reliance on patient recall of past events or symptoms, and inadequate patient completion of all questions. Our questionnaires only asked about a patient's current situation, however, and thus did not rely on patient recall of past compliants or events. Furthermore, no questionnaires in our study were incomplete regarding present financial status.

Previous investigations studying the use of questionnaires have validated their usefulness in the evaluation of outcome.[5,7,29] Moreover, it has been suggested that physician assessment of patient function may yield a higher score than a patient's self-report.[17] Our study relied on a patient's self-report of function and was not biased by physician assessment.

It is significantly difficult to compare the description of levels of functional outcome reported by any one individual study with the variation of such description presented in the literature. The categories of functional outcome used for patient self-reporting in this study had clearly definable criteria. Whereas Weber's criteria[39,40] were based solely on patient satisfaction, ours depend both on a patient's demonstrated ability to function at various task levels and on a patient's self-assessment of symptoms. Both our "Good" and "Excellent" outcomes fit Weber's "Good" category.[39,40] He defined this group as being completely satisfied. All of our "Good" and "Excellent" outcomes categorized themselves as completely satisfied.

Weber[39,40] also reported that his surgically treated patients fared better in the first year than his nonsurgical group. It is interesting that, in our study, the nonoperatively treated group achieved their success within the first year. This group had an average sick-leave time of 15.2 weeks compared with Weber's group of surgically treated patients, who averaged 11 weeks of sick-leave time, and 50% of the nonoperative patients reported less than 1 week of sick-leave. In Weber's study, however, 24 of the surgical patients required in excess of 3 months sick-leave time. Hurme and Alaranta[14] reported on a group of patients with HNP who underwent surgical disc excision. Their group had an average sick-leave time of 54 preoperative days and more than 78 postoperative days. However, 10% of that group required an additional 45 days sick-leave beyond the group average.

Return to work (RTW) rates have been considered one of the most important objective criteria of functional outcome. We report a RTW rate of 92% in our group of patients, with 90% of the patients returning to their previous occupations. Additionally, 86% of our worker's compensation patients returned to work. This compares favorably with previous surgical studies. Hurme and Alaranta[14] reported an RTW rate of 85%, and a 12% job change rate. Frymoyer et al[8] reported a 75% RTW in a group of patients who underwent disc excision. Kahanovitz et al[15] recently presented data on a group of patients who underwent disc excision and quoted a 77% RTW rate, with 65% returning to their previous jobs.

Disc extrusion has been considered a condition requiring surgical intervention, especially when accompanied by neurologic loss and positive SLR.[2,31-33] Our study contained a subgroup of 15 (26%) patients with an extruded disc fragment documented on CT scans. Eighty-seven percent (13 of 15) of these patients in our study had "Good" and "Excellent" outcomes. The average sick leave time for this group was 2.0 months, and 92% of these patients returned to work. Therefore, it appears that disc extrusion by itself is not an adequate indication for surgery.

Sixty percent of our patients had weakness demonstrated on physical examination, and all had documented radiculopathy on EMG testing. This 64% had no discernible difference in outcome from our study population as a whole. Eighty-four percent of these patients achieved "Good" or "Excellent" outcomes. We did not consider patients with a nonprogressive neurologic deficit (ie, significant weakness) to be surgical candidates without an adequate trial of nonoperative care. Any patients with a progressive neurologic deficit (one patient in this study) were sent to surgery without delay. The Weber[39,40] study, by comparison, automatically selected patients with "profound" weakness for the surgical treatment group, whereas we did not. Our patients probably represented greater neurologic impairment than his nonoperative group. To argue, therefore, that our group of patients were less impaired than those in previous investigations would not appear to be valid.

Of the subgroup of patients in this study who sought a second opinion regarding surgery, 15 patients achieved "Good" or "Excellent" results. All 15 returned to work, and had an average of 13.6 weeks sick-leave time. Although three patients required surgery, this represented an 83% success rate for aggressive conservative treatment. Despite the small size of this group, the implication is clear; alternative treatment for many patients undergoing discectomy for herniated disc in the absence of stenosis may be quite effective.

The optimum time for conservative care before surgical intervention has been said to be between 6 and 8 weeks.[14,31,32,33,39,40] Hurme and Alaranta[14] reported a poorer outcome in those patients in whom surgery was delayed beyond this time. However, a significant portion of our nonsurgically treated patients did not achieve their maximal functional outcome, before 12 weeks of treatment. Additionally, our patients who underwent surgery after 16 weeks all achieved "Excellent" or "Good" outcomes. Passive conservative treatment will lead to progressive deconditioning, and may thereby result in greater functional disability. However, active physical rehabilitation will enhance conditioning and function, thereby improving prognosis whether surgery is necessary or not.

In summary, this study demonstrates that patients with HNP and radiculopathy can be successfully treated nonoperatively. Moreover, the sick-leave time and RTW rates in our nonoperatively treated patients were superior to rates reported for similar patients treated surgically in previous studies. The presence of weakness did not adversely affect outcome in our group. Disc extrusion was successfully managed in 13 out of 15 cases (87%). Improvement occurred well within the first year as noted by the average sick-leave time. Four out of six patients who failed nonoperative treatment were found to have stenosis at subsequent lumbar spine surgery. It appears that HNP combined with stenosis carries a different prognosis than HNP without stenosis.

The question arises regarding the physiologic mechanism for the observed difference in the subgroup with stenosis. Theoretically, stenosis causes an interruption in blood flow to the nerve root, with resultant venous congestion, ischemia, axonal damage, and eventual intraneural fibrosis.[20,23,28,30] The compression created by "pure" HNP may be a reversible phenomenon based on changes in the initially high water content of the disc material. Gradual dessication of the disc material[12,13,27,34,37,38,42] would relieve the compression and serve as the explanation of the reversal of neurologic loss in the absence of surgical removal of the offending disc. As long as intraneural fibrosis can be avoided, axons have the capacity to regenerate in this type of lesion.[35]

Inflammation caused by the presence of nuclear disc material in the epidural space can add to nerve injury in two ways: 1) direct toxic injury to the nerve root by the chemical mediators of inflammation,[9,21,22,26] and 2) amplification of intra- and extraneural swelling with resultant venous congestion and conduction block.[20,36] As the inflammatory stage is controlled, these two mechanisms are resolved and neural function has the opportunity to return to normal.

Local circulation changes secondary to inflammation theoretically could cause an extruded disc fragment or contained herniation to maintain its high water content, thereby maintaining the compressive injury. Resolution of inflammation therefore would allow for further resolution of compression by several mechanisms. The duration of vascular compromise to the nerve root therefore would be less in this situation than in the presence of stenosis.

The reversibility of the neural injury of "pure" HNP is consistent with this theory. Although extruded disc material should have a greater capacity for dessication than contained herniations,[12,13,18,38] the presence of stenosis does not allow for the compression to be relieved. As the disc dehydrates,[1,34,37,42] there may be an increase in compression by the bony elements. This phenomenon may explain why progressive neurologic loss is not uncommon with spinal stenosis, but is rare in cases of "pure" HNP.

CONCLUSIONS

1) Lumbar HNP can be treated nonoperatively with a high degree of success.

2) Failure of passive nonoperative treatment is not sufficient for the decision to operate.

3) The presence of weakness does not adversely effect the outcome of nonoperative treatment, and should not be used as overwhelming evidence that surgery is necessary.

4) The presence of disc extrusion does not adversely effect the outcome of nonoperative treatment and should not be used as overwhelming evidence that surgery is necessary.

5) The premise that operative patients fare better in the first year is contrary to our results.

6) Failure to improve with aggressive nonoperative measures suggests the presence of stenosis, and should probably warrant greater decompression than purely disc excision or nuclectomy.

7) High surgical volumes of "simple" disc excisions or nuclectomies probably represent overtreatment in a group that carries a favorable prognosis in the short- and long-term by nonoperative treatment.

8) The decision to operate should be based on the patient's level of function and whether that functional level can be improved by an aggressive active rehabilitation program, rather than on imaging studies and/or physical examination findings.

APPENDIX

Program Description. *Pain Control.* Decisions for use of pain control methods were guided by a patient's level of function, and his or her ability to comply with the exercise program. All patients were enlisted in a therapeutic exercises regimen (Figure 1) as tolerated by their levels of pain and neurologic loss. The initial aspect, back first aid, involved the application of ice, resting in a position of comfort, and basic instruction in body mechanics to facilitate pain-free movement getting in and out of chairs, cars, bathtubs, etc. Back school instruction was initiated during this period, the patient being taught to control pain and muscle spasm using back school methods. The use of medications was kept to a minimum. Transcutaneous nerve stimulation also was frequently used for pain control. Acupuncture was occasionally used during this phase. A trial of extension exercises was used in each case. When the extension exercises caused centralization of low-back pain without exacerbating the radicular pain, they were continued. Peripheralization of the pain served as a contraindication to the continuance of extension exercises. This finding may indicate stenosis, far lateral disc protrusion, or posterior element pathology. The correction of a lumbar list was necessary before beginning extension exercises. If the exercises were attempted while the patient was still listed, exacerbation of pain often occurred. A trial of traction (gravity inversion, pelvic traction, or auto-traction) was used with patients having refractory radicular pain following extension exercises. Traction was continued in those patients who had a marked reduction of radicular pain during the trial.

Non-narcotic analgesics (ie, acetominophen) and NSAIDs (nonsteroidal, anti-inflammatory drugs) were frequently prescribed. Occasionally, a limited course (up to 2 weeks) of a Class 3 narcotic analgesic such as Tylenol (McNeil Consumer Products Co., Fort Washington, Pennsylvania) with codeine was prescribed. No patients received a Schedule II medication, a sedative hypnotic, or a muscle relaxant.

Prescribed bed rest was not used. Patients were instructed to pursue a level of activity that did not exacerbate their radicular pain or worsen a neurologic defict.

Persistent radicular pain was treated with corticosteroid therapy. Epidural injection was the treatment of choice, although in some patients a tapering course of oral corticosteroids was used. The caudal route of injection was used for disc herniation at the L4-5 and L5-S1 levels. A translumbar approach was used for disc herniations L3-4 and above. Localization by instillation of nonionic contrast material under flouroscopic guidance was used in

Treatment Phases

- **Pain Control**
  - Back First Aid
  - Trial of Extension Exercises
  - Trial of Traction
  - Basic Stabilization Exercise Training
  - NSAIDs
  - Non-Narcotic Analgesics
  - Corticosteroids
    - Oral
    - Epidural Injection
    - Selective Nerve Root Injection
    - Facet Injection
- **Exercise Training**
  - Soft Tissue Flexibility
    - Hamstring Musculotendinous Unit
    - Quadriceps Musculotendinous Unit
    - Iliopsoas Musculotendinous Unit
    - Gastroc-Soleus Musculotendinous Unit
    - External and Internal Hip Rotaters
  - Joint Mobility
    - Lumbar Spine Segmental Mobility
    - Hip Range of Motion
    - Thoracic Segmental Mobility
  - Stabilization Program
    - Finding Neutral Position
    - Sitting Stabilization
    - Prone Gluteal Squeezes
    - Supine Pelvic Bracing
    - Bridging Progression
      - Basic Position
      - One Leg Raised
      - Stepping
      - Balance on Gym ball
    - Quadriped
      - With Alternating Arm and Leg Movements
    - Kneeling Stabilization
      - Double Knee
      - Single Knee
      - Lunges
    - Wall Slide Quadriceps Strengthening
    - Position Transition with Postural Control
  - Abdominal Program
    - Curl-Ups
    - Dead Bugs
    - Diagonal Curl-Ups
    - Diagonal Curl-Ups on Incline Board
    - Straight Leg Lowering
  - Gym Program
    - Latissimus Pull Downs
    - Angled Leg Press
    - Lunges
    - Hyperextension Bench
    - General Upper Body Strengthening Exercises
    - Pulley Exercises to Stress Postural Contol
  - Aerobic Program
    - Progressive Walking
    - Swimming
    - Stationary Bicycling
    - Cross Country Ski Machine
    - Running
      - Initially Supervised on a Treadmill

all cases. Straight leg raising was assessed at the peak of local anesthesia (0.5% lidocaine final concentration in a 10 cc volume). If no relief occurred during this phase, a selective nerve root injection with corticosteroid was performed at the root level of greatest involvement (as determined by electromyographic study and CT findings). The results of injection therapy were assessed at 2 to 3 weeks. If disabling radicular pain persisted, epidural corticosteroid injection was repeated. Patients having persistent back pain consistent with facet sydrome underwent facet joint corticosteroid injections. Injection therapy was used to facilitate the patient's functional progress. Decisions to inject or reinject were based on a patient's ability to progress with the active exercise program.

Exercise Training. The key element in the phase for exercise training, called Stabilization Training, was to attain adequate dynamic control of lumbar spine forces to eliminate repetitive injury to the intervertebral discs, facet joints, and related structures. Stabilization exercise routines were divided into basic and advanced levels. The basic level of postural control began with supine and prone positions. Training of dynamic control was then advanced to kneeling, standing, and to position transition movements. Meticulous technique for exercise performance was considered paramount. Initially the exercises were carried out with one-on-one instruction, and then advanced to a class situation. Each of the exercises was designed to develop isolated and co-contraction muscle patterns to stabilize the lumbar spine in neutral position, a position needing to be individually defined for each patient. Neutral spine did not necessarily mean 0° of lordosis, but rather a modification of lordosis that most satisfactorally reduced the patient's radicular pain. The exercise trainer used a hands-on technique to facilitate optimal posture while the patient was progressively challenged by more advanced exercises. Emphasis was placed on the maintenance of proper form during performance. To ensure engram* motor programming, precise repetition of movements were monitored.

Prior to strengthening exercises, soft tissue flexibility and joint range of motion was addressed. Flexibility training was focused on the musculotendinous units of the hamstrings, quadriceps, Iliopsoas rectus femoris, external and internal hip rotators, and gastroc-soleus. Strict attention was paid to maintenance of neutral spine posture while performing stretching exercises, which were carried out on a daily basis. Stretching was first performed passively by the exercise trainer and then became part of the patient's home program. Continued active assistive stretching was occasionally necessary to fully overcome soft tissue contracture that resulted from limited mobility and nerve root irritation.

The patient was trained in active joint mobilization methods, such as extension exercises in prone and standing positions, as well as alternating mid-range flexion and extension exercises while in a four-point stance.

Abdominal muscle strengthening was initiated with simple curl-ups. This progressed to dead bugs, an exercise that uses alternate arm and leg movements while lying supine, contracting the abdominal musculature and holding the spine in neutral position. Further progression included diagonal curl-ups, and diagonal curl-ups performed on an inclined board. Once the patient was able to carry out three sets of 15 repetitions, the exercise was advanced. Finally, lower abdominal muscle strengthening was emphasized with straight leg lowering exercises.

Demonstration of proper form and technique was necessary for the individual to graduate from the basic level. These same principles were then applied to the weight-training portion of the program. The patient was taught how to get on and off weight training equipment while continuing to adhere to stabilization principles. Additionally, the patients were

*An engram is a neurophysiologic phenomenon that describes the motor information necessary to perform a complex movement. All of the individual components of a complex motor act are stored together as a unit forming an engram. These data, which are stored in the motor cortex, are retrievable without the need for conscious control.

taught to control spine posture while changing the weight stack resistance pin on the machines, as well as while lifting and racking free weights. The patient was then taught how to use resistance equipment, including free weights, pulleys, and single-station weight machines. Co-contraction of the lower abdominal muscles was reinforced to maintain optimal neutral spine posture during the performance of weight training. Each individual strengthening program was tailored to the patient's needs. The weight training program was not geared solely towards the truncal musculature but taken a step further to a total fitness program.

Aerobic and anaerobic training was incorporated into this total fitness program. Aerobic conditioning was initiated early in the program in the form of walking. This was rapidly advanced to stationary bicycle riding, and/or use of a cross-country ski machine.

Swimming was encouraged for those patients interested in this mode of training, but was not uniformally used with all patients. These activities were first performed under supervision to ensure maintenance of neutral spine posture. Patient instruction while riding a stationary bicycle, while running on the treadmill, and while swimming were integral portions of the program. We utilized one-on-one instruction to emphasize proper neutral spine posture while the patient performed each one of the activities. Many patients were advanced from treadmill walking to treadmill running, and finally to supervised running on a track. Once the patient was able to demonstrate adequate neutral spine stabilization, supervision was no longer necessary. Training levels were tailored to the patient's age, medical history, and level of aerobic conditioning according to previously established American College of Sports Medicine guidelines.

Decisions for advancement of the program were based on functional progress rather than pain level. The program end-point was determined by a maximal functional improvement that could not be advanced by further exercise training or pain control methods.

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