Focus on the Spine

THE CLINICAL EFFECTS OF INTENSIVE, SPECIFIC EXERCISE ON CHRONIC LOW BACK PAIN: A CONTROLLED STUDY OF 895 CONSECUTIVE PATIENTS WITH 1-YEAR FOLLOW UP

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ABSTRACT

Eight hundred ninety-five consecutive chronic low back pain patients were evaluated. Six hundred twenty-seven completed the program. One hundred sixty-one began, but dropped out, and 107 were recommended for treatment but did not undergo treatment for various reasons. Average duration of symptoms prior to evaluation was 26 months. Forty-seven percent of patients were workers' compensation patients. The primary treatment was intensive, specific exercise using firm pelvic stabilization to isolate and rehabilitate the lumbar spine musculature. Patients were encouraged to work hard to achieve specific goals. Seventy-six percent of patients completing the program had excellent or good results. At 1-year follow up 94% of patients with good or excellent results reported maintaining their improvement. Results in the control group were significantly poorer in all areas surveyed except employment.

Chronic low back pain is a pervasive and costly problem in the United States, as it is in the rest of the industrialized world. The scope of this problem continues to grow despite our best efforts. By some estimates, low back pain costs over 40 billion dollars per year.[1-6] Further, workers' compensation disability for low back pain is growing at 14 times the population growth[6] Finally, and most distressing, only 15% of patients with back pain account for 85% of these enormous costs.[7]

The traditional approach to management of sub-acute and chronic back pain has been passive modalities. The modalities may have changed, but the results have remained mostly disappointing. By the mid-80s, evidence began to appear suggesting an aggressive "sports medicine" approach was more effective than traditional methods in this patient group.[1,8-11]

It was our purpose, therefore, to test the efficacy of a specific, aggressive program in our patients with low back pain. In 1990 the authors began a prospective study to look at the objective results in a large number of patients treated with aggressive exercise.

The working hypothesis was chronic low back pain could be treated effectively using intensive, specific exercise. Intensive was defined as muscular exercise (eg, lumbar extensors) against dynamic resistance to volitional failure, ie, exercise performed on a strength training device through a full range of motion. The exercise activity was continued for as many repetitions as possible, so long as the patient could maintain full range of motion (ie, the range of motion demonstrated during the first repetition). Specific was defined as exercise

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Table 1

REASONS FOR QUITTING TREATMENT	
Reason for Quitting	%
Felt the program wasn't helping	41%
Was doing well and didn't feel more treatment was necessary	27%
Transportation difficulties or lack of time	16%
Told by insurance company or other doctor to stop	8%
Thought program was too expensive	3%
Other	5%

Fig 1: Patients categorized by diagnosis. LS strain/mech=lumbar strain or mechanical low back pain. DDD/DJD=degenerative disk disease or degenerative arthritis; LDS=lumbar disk disease; Spondylo=spondylolisthesis or spondylolysis; Other=inflammatory arthritis, juvenile diskogenic disease, fibromyalgia, etc.

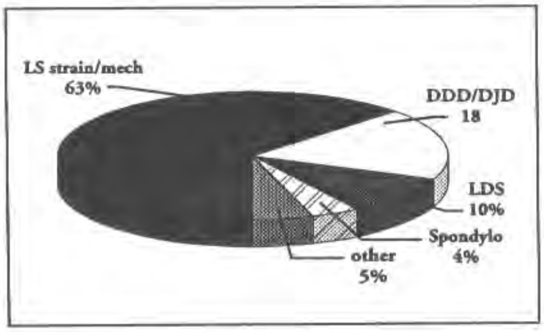
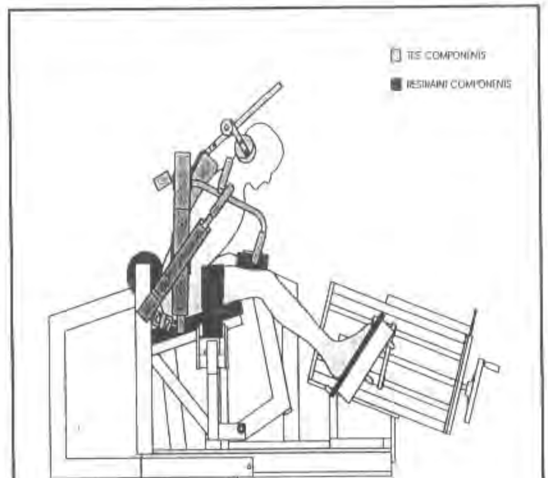


Fig 2: Specific lumbar testing and rehabilitation was performed in a MedX lumbar-extension machine. Pelvis fixed, spine in flexion (A); pelvis fixed, spine in extension (B); full schematic, patient neutral (C).



Pelvis fixed, spine in flexion

Fig 2A.

with the pelvis immobilized so as to isolate the lumbar extensor muscles.

We were trying to answer the following questions:

1. Can chronic low back pain be treated effectively?
2. Is intensive, specific exercise with pelvic stabilization more effective than passive modalities and light exercise not using pelvic stabilization?
3. Does diagnosis matter?
4. Does leg pain, radicular or referred, respond to intensive, specific exercise?
5. Does objective spinal function correlate with subjective complaints of pain in the back and/or leg?
6. If objective and/or subjective gains are made, are they enduring or do patients tend to relapse and then reutilize the health care system?
7. Is intensive-specific exercise safe?
8. Is intensive-specific exercise cost effective?

Materials and Methods

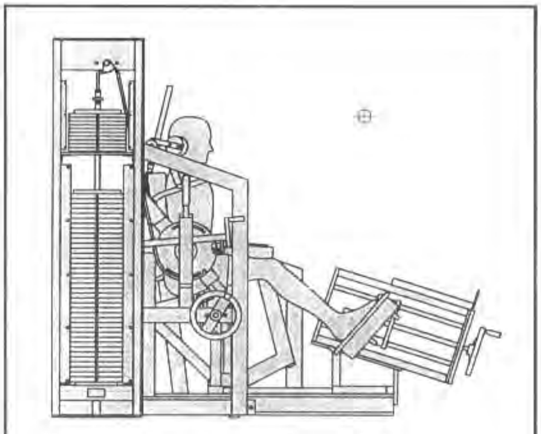
Eight hundred ninety-five consecutive patients referred for rehabilitation between the ages of 14 and 65 (484 males of average age 38.7, 411 females of average age 37.1) were evaluated for lumbar disease. The vast majority were referred by other providers familiar with our clinic and our aggressive approach. We excluded patients over age 65 or under age 14. Six hundred twenty-seven patients completed the program. One hundred seven patients were evaluated and recommended for inclusion into the program, but for various reasons did not enroll and attempted a different type of treatment. Typically these reasons were either logistical or insurance-related. These 107 patients constituted the control group. One hundred sixty-one patients began the program, but dropped out before completion for various reasons. Table 1 shows the reasons cited for quitting treatment in the 122 patients (76%) available for follow up.

Average duration of symptoms prior to evaluation was 26 months (range:-3 months to 30 years). Forty-seven percent of the patients were workers' compensation patients. On average, the patients had seen three previous providers for evaluation or treatment and had an average of two diagnostic tests (range: 0 to 10). Fourteen percent had had previous surgery, and the average number of surgeries in this group was 1.7. These patients had tried an average of six different treatments, and 89% of the patients had already failed a "supervised exercise program." Forty-seven percent had tried and failed chiropractic.

Fig 2B.

Pelvis fixed, spine in extension

Fig 2C.


Full schematic, patient neutral

At the initial evaluation, 36% were employed without restrictions, 24% with restrictions, 22% were unemployed secondary to their back problem, 10% were unemployed, and 7% were either students, retired, or disabled for another reason.

Primary diagnoses are shown in Figure 1.

Specific lumbar testing and rehabilitation was performed in a MedX lumbar-extension machine (Fig 2) and a MedX Torso-Rotation machine (MedX Corporation, Ocala, Fla). Patients were tightly restrained to lock the pelvis in place (Figs 2A-2B are shown without the weight stack, counterweight, or electronics; 2C shows a schematic of the entire apparatus). This restraint system isolated sagittal movement to the lumbar spine and prevented other muscles (eg, hamstrings, glutei) from contributing to measured torque values. Counter weighting was used to correct for gravity's effect on upper torso weight. Testing results using MedX equipment have previously been shown to be valid and reliable.[12-17]

Patients required an average of 18 visits to complete the program (range: 4 to 35). Treatment was ended when any of the following criteria were met:

1. The patient was pain-free or nearly pain-free, and objective functional levels were at or near normal.
2. The patient was no longer making objective gains in spinal function.
3. The patient refused to cooperate or give a good effort.

Patients were treated an average of twice per week. Each session lasted approximately 1 hour, and the patient was supervised by physical therapists throughout. The mainstay of the treatment involved progressive, resistive exercises of the isolated lumbar spine with the pelvis firmly stabilized. Patients also did aerobic exercise and strength training of other muscles (abdominals, hamstrings, glutei) at each visit. Previous studies have shown that in patients with chronic back pain the lumbar extensor muscles are more likely to show relative weakness than the abdominals; therefore, efforts at strengthening were concentrated here.[17-20]

Education was considered important and, therefore, all patients were required to watch educational videos, learn body mechanics, and read specific literature. Upon discharge all patients were given a home exercise device (Lifeline Gym™) and taught a home program of progressive resistive exercises of the trunk muscles. Technique was emphasized (ie, extending the lumbar spine rather than extending the pelvis). The goal of the home program was to allow the patient to continue exercising independent of the health care system and not have to purchase home equipment or join a health club. We have no problems with home equipment or health clubs, but this was not feasible for many of our patients. We wanted no excuses for lack of exercise.

See Appendix for details on the typical rehabilitation schedule. Every 3-4 weeks, another isometric test was done to chart progress. Progress also was charted in sagittal and rotational range of motion and sagittal and rotational dynamic work capacity. Treatment continued until one of the above three criteria was met. Upon discharge patients were asked to rate their back pain and/or their leg pain in one of the following categories: resolved; greatly improved; improved; slightly improved; unchanged; worse. Patients also were required to rate their functional ability in the activities of daily living using the same scale. At an average of 13 months post-discharge (range: 7 to 18), a questionnaire was mailed to all patients inquiring about their status. Patients who failed to return the questionnaire were phoned. Cost data were obtained from the billing department.

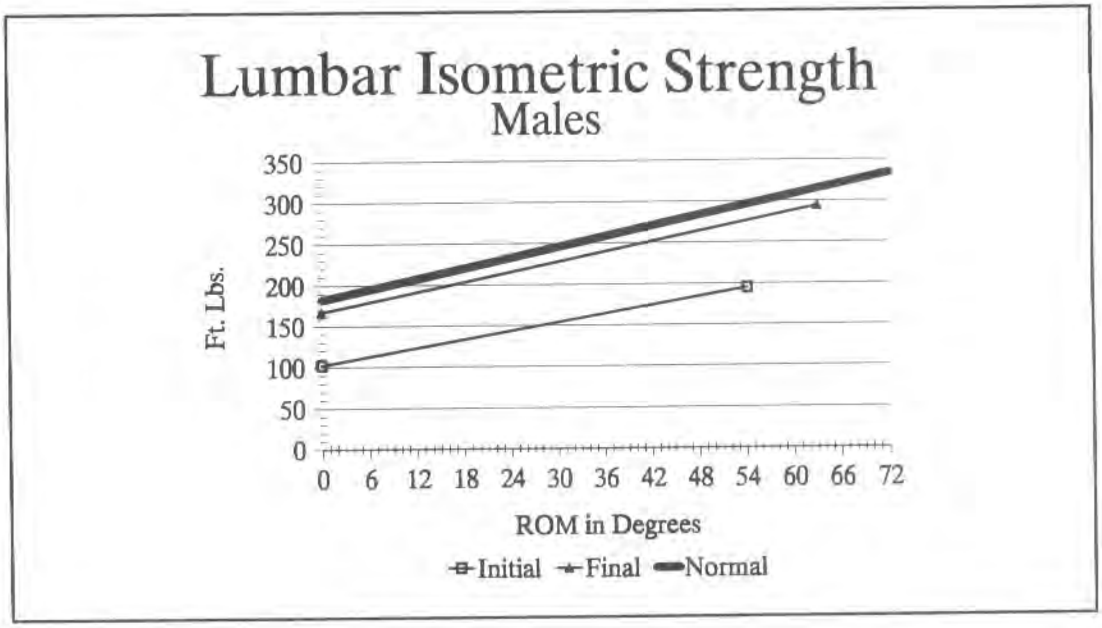


Fig 3: Lumbar isometric strength in males.

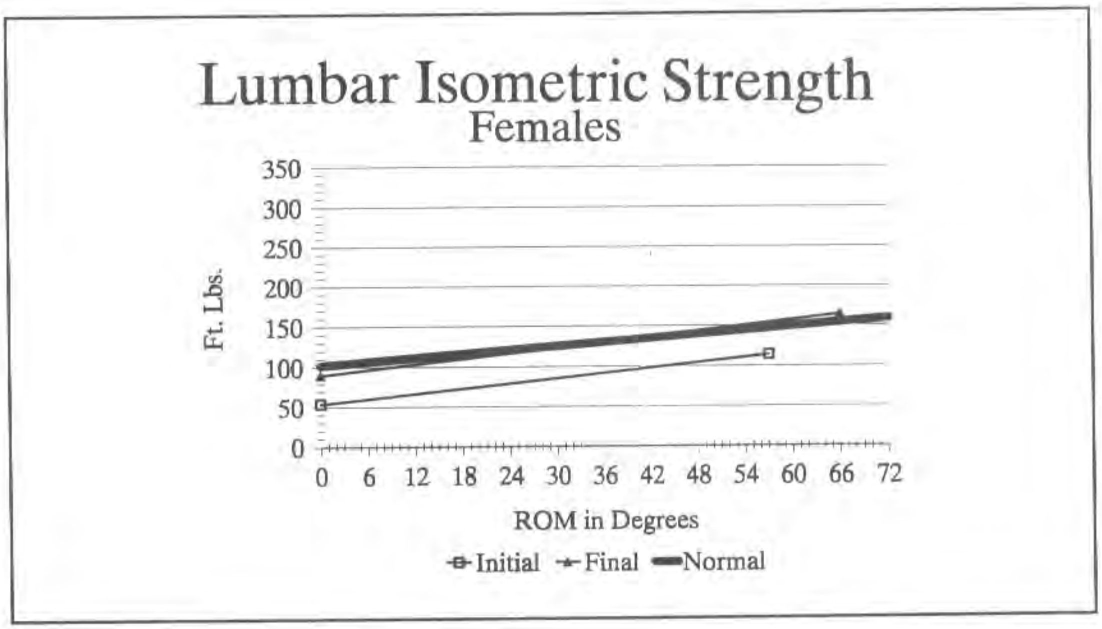


Fig 4: Lumbar isometric strength in females.

Statistics were compiled using SPSS/ Windows. Two-tailed *t*-tests were used to analyze interval grouped data. The Pearson correlation coefficient was used to evaluate the relationship between strength and pain. Nominal variables were analyzed using chi-square methods.

Results

Static strength. Static strength showed significant ($P<.001$) improvement throughout the range of motion in both males and females. The data are summarized in Figures 3 and 4.

Range of Motion. There was a significant ($P<.001$) increase in sagittal range of motion. These data are summarized in Table 2.

Dynamic strength. Dynamic strength showed significant ($P<.001$) increases in both the sagittal and rotational planes. These data are summarized in Figures 5 and 6.

Low back pain. A total of 602 patients listed low back pain as a significant complaint when beginning the program. For 64% of patients, there was a substantial decrease in the perception of pain in the low back which in many cases was dramatic. Pain was decreased in 15%, slightly

Table 2

RANGE OF MOTION	
ROM	Degrees
Initial ROM	54°
Final ROM	63°
Percent Change	+17%

improved in 6%, no change in 12%, and was worse in 3%.

Leg pain. There were a total of 429 patients who listed leg pain as a significant problem on the initial evaluation. Leg pain was considered to be pain below the buttock, but was not sub-divided into pain above or below the knee or unilateral or bilateral pain. For 62% of patients, there was a substantial decrease in leg pain, and again, many times the improvement was dramatic despite years of problems. In 17% leg pain was decreased, in 6% it was slightly decreased, in 13% there was no change, and in 2% it was worse.

Perceived functional response. In the group of 627 patients who complained of back pain, 71% had a substantial improvement in their perceived ability to perform the activities of daily living. In 22% it was somewhat improved, and in 7% no change.

Correlation between isometric strength and change in low back pain. The strength levels of patients in each of the pain categories mentioned above were averaged. There was a weak correlation (r=.318) between increasing strength levels and decreasing pain. When viewed graphically, however, the effect appears more prominent. Figure 7 shows the average strength level broken down by pain response for males. Results were similar in females.

Overall response. Response to treatment was graded as excellent (46%), good (30%), fair (14%), or poor (8%). To be rated as excellent or good, a patient had to have both substantial pain relief and substantial improvement in strength. A patient would have to rate their chief complaint as either resolved, greatly improved, or improved and would also have to show substantial increases in strength. Poor results would apply to patients who had slight or no pain relief and who gained little or no strength. Fair results were most often seen in that group of patients who had substantial strength gains but little or no pain relief.

There is a good rationale for this grading system. Patients seldom see a doctor because their backs are "weak." They seek medical attention because of pain. Therefore, in the opinion of the authors, without substantial pain relief it is difficult to call a result good or excellent. Studies often look

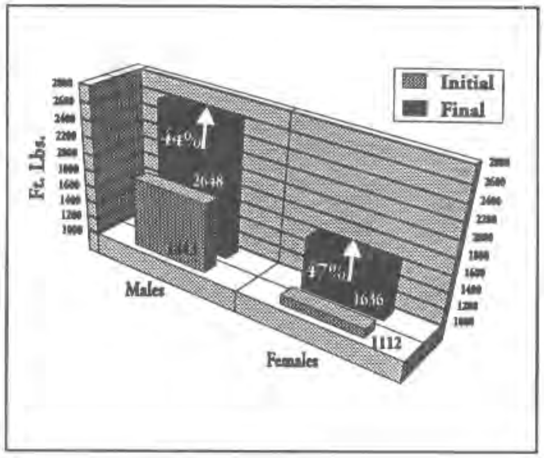


Fig 5: Work capacity—lumbar spine.

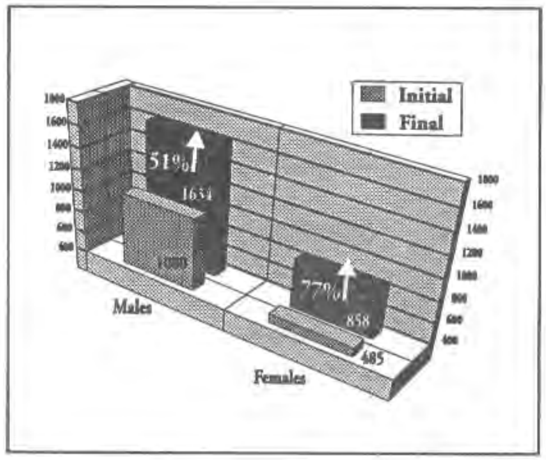


Fig 6: Work capacity—torso rotation.

at return to work as the best indicator of treatment effectiveness. But people may often return to work not because their condition has improved, but because of other external pressures. So while the criteria can be argued, the authors still believe this is a valuable, "real world" piece of information.

Specific sub-groups of patients. Diagnosis did not significantly affect results; however, psychosocial factors did. It is widely believed that patients involved in workers' compensation and/or litigation have poorer clinical outcomes than patients without the same potential secondary gain. This trial supports those beliefs. Also, in this trial, signs of symptom exaggeration in physical examination (Waddell Signs)[21] correlated negatively with results. But it was interesting to note that many patients who showed signs of symptom exaggeration at the beginning of treatment no longer showed those signs at the end. Figures 8 and 9 show the distribution of good or excellent results broken down into various categories.

Return to work—initial group. Of the 627 patients who completed the program, 139 were out of work for an average of 73 days at the time of pre-

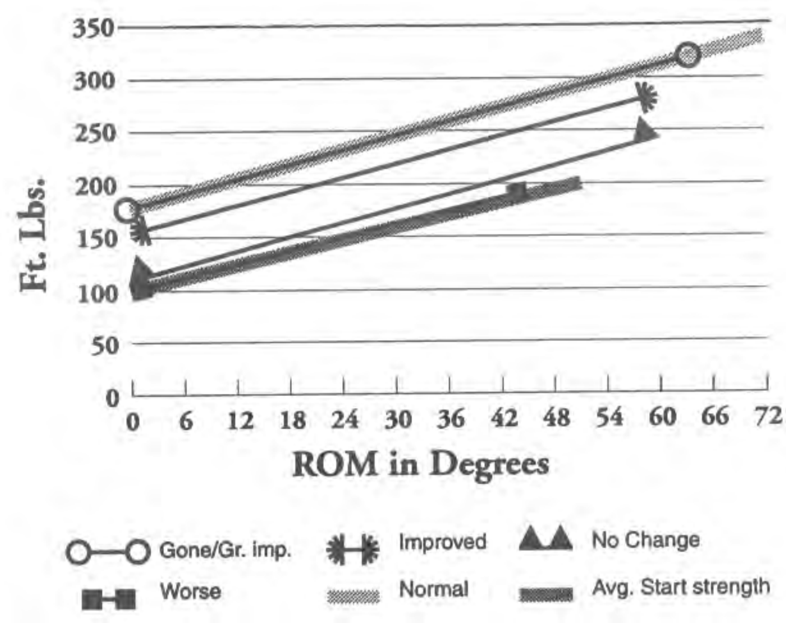


Fig 7: Relating strength to low back pain in males.

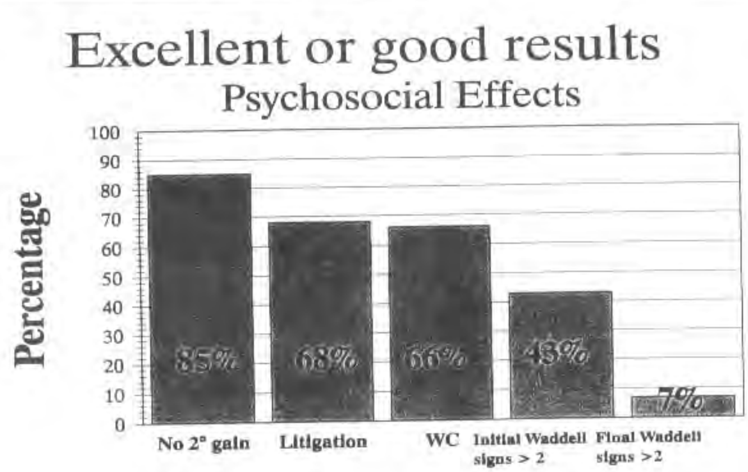


Fig 8: Excellent or good results—psychosocial effects.

sentation because of their lumbar disease. Figure 10 shows the results in this group. For approximately 22% the status after treatment was unknown. Usually this was because a referring physician was controlling the case. Even though in most instances we recommended a return to at least light work, our advice was only a recommendation. If the referring physician did not keep us informed (unfortunately this happened all too often), we could not be certain of the work status immediately after discharge. Obviously some of these people returned to work, but the exact number is unknown.

Follow up. Follow up was done at an average of 13 months post-discharge. Of the 627 patients who completed the program, 495 (79%) were available for follow up. Of the 161 who dropped out, 122 (76%) were available for follow up. Of the 107 patients in the control group, 83 (78%)

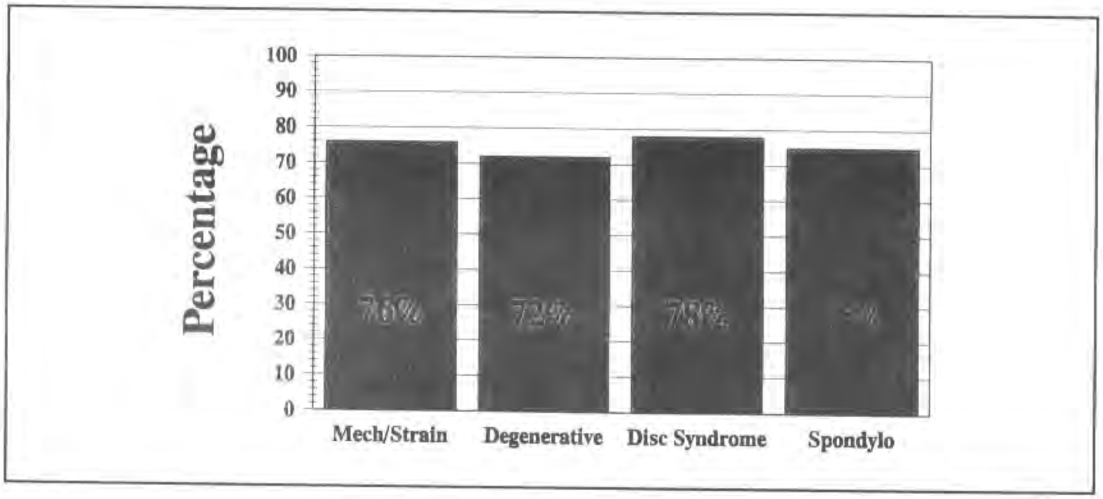


Fig 9: Excellent or good results by diagnosis.

were available for follow up. Patients were surveyed for current lumbar status, reutilization of the health care system, gainful employment, and compliance with the home exercise program.

Spinal condition at follow up was broken down into two groups: those with good or excellent results and those with fair or poor results. Of those with previous good or excellent results (N=345), 94% maintained improvement and 6% ceased to improve or became worse. Of those with previous fair or poor results (N=150), 25% improved; 75% were not improved or became worse.

Chronic spine patients tend to use the health care system repeatedly. We surveyed for reutilization and then broke down the responses into three groups: non-workers' compensation/litigation patients (13% reutilization); worker's compensation/litigation patients (25% reutilization); and >2 Waddell signs (76% reutilization). Waddell signs are signs of symptom exaggeration. These results are best understood when compared with the control group later in this report, but there was a definite trend toward higher utilization in patients with potential secondary gain.

Return to work—Follow up group. Initial study: 139 previously employed patients were not working due to spinal pain. They had been off work for an average of 73 days. Follow up was obtained in 109 (76%). At follow up, 77% of the patients were gainfully employed.

Compliance with home exercise program. Home exercise compliance is important in these patients. Our patients did not do very well. Fifty-three percent of patients used the LL gym exercise device we gave them; 47% were not using the LL gym device. Based on these data we have changed our program to better emphasize long-term home exercise.

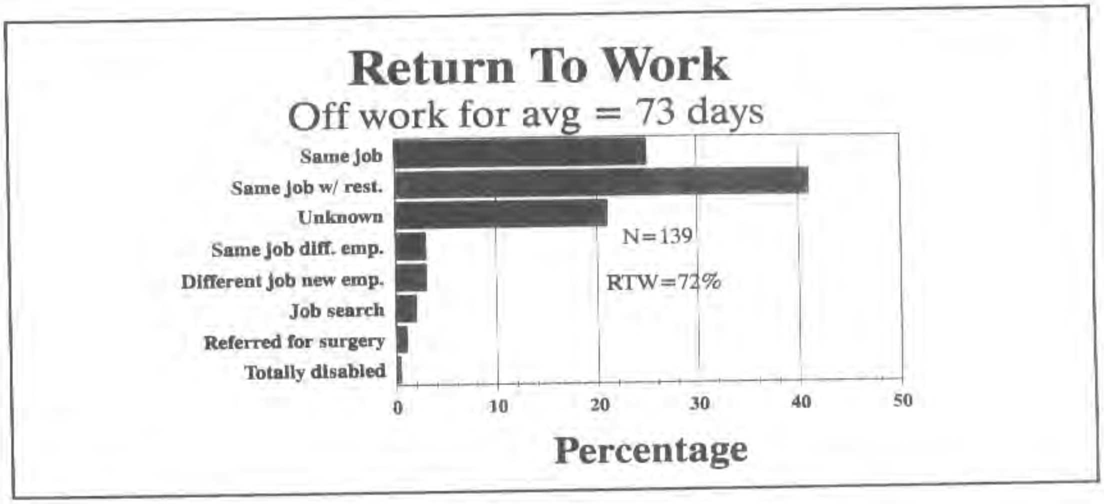
Control group. There were 107 patients felt to be good candidates for rehabilitation who did not participate. Usually, this was because of logistical difficulties or insurance problems. Occasionally, patients simply did not want to do "just another exercise program." There was no significant difference in this group of patients regarding age, duration of symptoms, or starting objective functional levels. Because this selection was not random (it was, however, consecutive), and because we did not control the treatment these patients received, this is not a true control group. Nevertheless, these patients were indistinguishable based on demographics or diagnostic factors, and following them up gave us valuable insight into alternative treatments and their success or failure.

The control group was surveyed for utilization of the health care system (13% of non-workers' compensation/litigation patients who completed the program reutilized the system vs 42% of controls; 25% of workers' compensation/litigation patients who completed the program reutilized the system vs 76% of controls), ability to get lasting relief from treatment (70% of patients who completed the program obtained substantial relief for at least 1 year vs 29% of controls), and work status (77% of those who completed the program were gainfully employed at follow up vs 78% of controls). There were significant differences ($P<.001$) between the treatment and control groups in all areas surveyed except employment.

Discussion

This trial supports the use of specific intensive exercise for chronic back pain patients. The presence or absence of leg pain did not alter the results. It confirms results reported by Risch et al in 1993.[11] The program was successful even though the vast majority of the patients had previously tried some form of exercise, most of them supervised exercise under the guidance of another health care provider.

Fig 10: Return to work (off work for an average of 73 days).



Bias was present in the selection process because most patients were referred by other providers familiar with our program. It is unknown how many patients these providers did not refer. This bias is somewhat mitigated by the fact that all these patients represent people with long-term chronic pain who have entered the system for treatment. That they *will* be treated is a given until doctors change and refuse to see chronic low back pain patients. In this respect the patients represent their own control group, because nearly all had tried and failed multiple treatment modalities. Yet most (70%) had good or excellent results that were maintained for at least 1 year.

This study suggests that not all exercises are created equal. It appears, in fact, that much of the exercise done is worthless for this group of chronic patients. It is our opinion that this is because so many patients did not follow through on their exercise or stopped exercising at the first hint of discomfort, believing they were doing damage. Many, if not most, of our patients experienced initial periods of discomfort as they vigorously exercised a weak and stiff lumbar spine. This discomfort was not unexpected,[1,22] but it was amazing how many patients had been advised to continuously decrease their activity levels and to let pain guide their activity level. Such patients become conditioned to avoid pain. This causes more deconditioning and more dependence on the health care system.

The other reason previous exercise was not helpful was because without pelvic stabilization it is almost impossible to meaningfully exercise the lumbar extensors. Graves[14] has shown that attempts to strengthen the lumbar spine using traditional equipment (eg, Nautilus™ or Cybex Eagle™) are completely ineffective. These and similar devices are capable of strengthening the pelvic extensors but not the lumbar extensors. Our study and others[18-20] have shown that lumbar extensor strength is a risk factor in long-term outcome, and this may explain why so many of our patients did well even though they had been doing exercises for months or years.

Firm pelvic stabilization has another important benefit: it forces patients to move a painful, stiff spine. Motion promotes healing in the musculoskeletal system, and lack of motion leads to stiffness, cartilage degeneration, and muscle atrophy. More recent evidence suggests that movement of the lumbar spine under load affects disk PH, which may also account for the pain improvement.[23]

During this study we observed that these patients limited their lumbar movement because of pain. Over time they had learned to perform tasks without lumbar movement such as bending at the knees, rather than at the waist, to pick up an object. They even learned to exercise without meaningful lumbar involvement by substituting pelvic movement for lumbar movement. Exercising with the pelvis firmly anchored forced the lumbar spine to move against resistance. Without such anchoring patients were too easily able to protect the lumbar area from meaningful exercise. In our opinion this is why many of the exercise programs were ineffective.

We made a very strong effort in this program to promote independence. Patients were encouraged to be active even if they had discomfort. When pain was severe, they were seen again by the physician and the physical therapist and, provided there had been no significant change in the physical examination (and this was most often the case), exercise was continued.

As the trial progressed, it became obvious that a supportive and encouraging atmosphere was critical. It also became very clear that visual evidence of objective progress was crucial to reinforce exercise. At the beginning of the exercise program, people often had some discomfort, and if they had not been able to observe objective strength gains on the individual graphs, we believe many would have quit. Patients needed lots of positive feedback to continue working hard at a program which initially did not always provide pain relief.

This brings up another important point. Table 1 shows that 41% of the patients who quit the program did so because they did not feel any better. Many of these quit after a week or two. The authors feel that at least some of these patients would have had a good outcome if they had finished the program. As mentioned previously, many patients began to feel better only after several weeks of aggressive exercise.

We believe reutilization is one of the best indicators of effectiveness. The patients in the control group reused the health care system at a significantly higher rate ($P<.001$) than the treatment group. It is this constant reutilization that to a large extent drives the cost. Any reasonably priced treatment that can decrease reutilization is cost effective.

Other authors have stated that a precise diagnosis is not possible in most of these patients.[5,6] We agree; however, this study suggests that exercise as a treatment is effective regardless of the underlying condition. Because of this the authors believe that much less effort and money should be spent on diagnosis. It makes more sense to rule out emergent conditions such as tumor, acute fracture, progressive neurologic deficit, visceral sources of pain, or infection rather than try to "rule in" a nonspecific source of pain. The emergent conditions can usually be excluded with a good history and physical. Resources are then more effectively devoted to treatment.

Initially, there were eight questions we were trying to answer.

1. Can chronic low back pain be effectively treated?

Answer: Seventy-six percent of patients had good or excellent results initially. Seventy percent had good or excellent results that were lasting at follow up.

2. Is intensive, specific exercise using pelvic stabilization more effective than passive modalities or light exercise not using pelvic stabilization?

Answer: Yes. On average our patients had tried and failed six different types of treatment. Eighty-nine percent had failed a previous exercise program.

3. Does diagnosis matter?

Answer: Diagnosis did not significantly affect outcome in this trial.

4. Does leg pain, radicular or referred, respond to intensive, specific exercise?

Answer: Initially, 429 patients listed leg pain as a substantial complaint. After treatment, 62% rated their leg pain as gone or greatly improved. Only 15% said their pain was unchanged (13%) or worse (2%).

5. Does objective spinal function correlate with subjective complaints of pain in the back and/or the leg?

Answer: Increasing lumbar extensor strength correlates weakly (r=.318) with decreasing subjective complaints of both back and leg pain.

6. If objective and/or subjective gains are made, are they lasting over time or do patients tend to relapse and then reutilize the health care system?

Answer: Overall, 76% of patients had good or excellent results. Of these, 94% reported at follow up that they had maintained all or most of their improvement.

7. Is intensive, specific exercise safe?

Answer: Yes. Other than occasional minor muscles strains, there were no injuries in this group of patients. People can exercise to failure and give maximum isometric efforts for testing at quite minimal risk.

8. Is it cost effective?

Answer: The average cost of the entire program including all physician fees and home exercise equipment was $2250. Programs for chronic lumbar pain usually cost much more, sometimes over $10,000. For comparison, in our city magnetic resonance imaging costs $1000, a diskogram $2000, and a single epidural injection $690. Even more than the cost, however, we believe reutilization of the health care system is a better measure of cost effectiveness. A program costing $10,000 to $15,000 would be very cost effective if the patient returned to gainful employment and stayed out of the health care system. But if a patient finishes or quits one treatment merely to begin another, then the efficacy must be questioned.

Currently, there is some debate about the need for expensive, computerized testing equipment to rehabilitate the lumbar spine. Some believe the cost is not justified and that results are just as good with low-tech equipment or home programs or health clubs. It is difficult to justify spending money on acute episodes, because the natural history of the disease is so favorable without any treatment at all. However, chronic pain is much different. The natural history is one of recurrence and continuous use of health care resources. For chronic low back pain a modest amount spent to prevent or alter the typical natural history would be very cost effective.

This study refutes the viewpoint that home exercise or the use of health clubs suffice in this patient group. Almost all of our patierts had tried "low-tech" exercise and failed. Whether or not the expense is justified depends on the value society puts on the treatment of chronic low back pain patients. But until we as a society decide that these patients are not worth treating, they will continue to utilize the health care system. Therefore, it is crucial to know how best to allocate our health care dollars. In this study, patients going through the program re-utilized the health care system at a significantly ($P<.001$) lower rate than the control group. Many patients, by their own report, were able to avoid surgery. It is certain that had these patients not been referred to our clinic, they would have been referred elsewhere. It is then likely they would have continued to receive treatments similar to what they had received in the past, as occurred with the control group. Many would likely have had surgery.

In a large number of chronic low back pain patients, the pain is iatrogenically exacerbated. By encouraging passive modalities we make patients dependent on the health care system for a limitless stream of "feel good" treatment. Giving in to pain and trying to live one's life to avoid discomfort does not promote improved health. Instead it promotes helplessness, loss of self esteem, deconditioning, depression, and soaring health care costs. A better alternative is aggressive activation while encouraging the patient to try to do more, not less.

This study suggests that aggressive exercise is a valuable, cost effective treatment for chronic low back pain. Direct comparisons among patients with similar conditions treated in different ways is important. The goal should be agreement among health care professionals on proper management of this difficult condition. This would include agreement on when to use imaging, surgical indications, when care should be ended, and what type of care is indicated at each step of the case.

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Appendix

Visit I, Week I: Patients started out stretching and then did aerobic work on both an upper body ergometer (UBE) and an isokinetic bike followed by accessory muscle strengthening. They were then placed in the MedX lumbar extension machine, and low level, dynamic exercise with variable resistance was performed (see Fig 2). A short practice test was done to acclimate the patient followed by a static test performed at equidistant points throughout the possible range of motion to identify the starting strength level for each patient. Patients were encouraged to give a maximum effort.

Visit II, Week I: The patient repeated the previous stretching, accessory muscle strengthening, and warm-up aerobic exercises. In the same MedX lumbar-extension machine, the patient performed a dynamic exercise session with the pelvis firmly fixed, thereby using only the muscles of the isolated lumbar spine. The patient was encouraged to work hard but not to the point of failure. When the patient felt he or she was getting close to failure, exercise was stopped. Next, the patient was stabilized in the MedX torso-rotation machine. The pelvis was stabilized and an appropriate weight selected. The patient then rotated the trunk against variable resistance from right to left and from left to right until failure. The number of possible reps times the amount of weight was recorded; this was the initial starting dynamic rotational work capacity.

Visit I, Week II: After the appropriate warm-up, stretching, and accessory muscle strengthening, the patient was stabilized in the MedX lumbar-extension machine and dynamic exercise was performed to failure. This established a baseline. Next, the patient was stabilized in the MedX torso-rotation machine and dynamic exercise was performed, but not to the point of failure.

Visit II, Week II: After appropriate warm-up, the patient was placed in the MedX lumbar-extension machine and dynamic exercise was performed to just short of failure. The patient was then stabilized in the torso-rotation machine and the trunk rotator muscles were exercised to the point of failure.