Critical Evaluation of the Results of Lumbar Sympathectomy *

D. E. STRANDNESS, JR., M.D., J. W. BELL, M.D.

From the Veterans Administration Hospital, Seattle, Washington

Introduction

THE RESULTS of lumbar sympathectomy in the treatment of intermittent claudication range from a low figure of 13 per cent of patients improved to a high of 85 per cent.[2, 4, 6, 8-13] This extreme discrepancy in statistics largely explains the continued controversy and confusion concerning the true value of the operation. As Mavor [11] stated, in 1955, "Probably the greatest problem lies in acquiring a reliable postoperative yardstick with which to measure improvement." For example, on the basis of our patients' subjective evaluation, we previously reported a figure of 58 per cent improvement.[17] However, subsequent experience with objective methods of evaluation indicates a much less favorable picture.

The purpose of this report is to present objective methods of evaluation as a more meaningful and valid assessment of the value of lumbar sympathectomy for intermittent claudication.

Material and Methods

In 1959, patient evaluation with digit plethysmography was begun in an attempt to determine which patients might benefit from lumbar sympathectomy.[18] The plethysmographic data were not used to alter our general clinical indications for sympathectomy. In each case the procedure consisted of removal of the sympathetic chain from L_2-L_4.

This study includes 39 sympathectomies in 29 patients with arteriosclerosis obliterans. Only one patient in this group had diabetes mellitus. Thirty-four of the sympathectomized limbs have been followed longer than six months. Table 1 shows the level of palpable pulses in these patients.

The mercury strain-gauge plethysmograph was used throughout this study.[18] Studies were carried out in the immediate preoperative period, during the first postoperative week and at six monthly intervals. The same study program was carried out in all patients:

1. *Segmental Pressure Studies:* Systolic blood pressures were obtained with pneumatic cuffs placed successively on the upper thigh, above the knee, below the knee and at the ankle. At each level the pressure in the cuff is raised above systolic blood pressure and gradually lowered until digit blood flow is restored as noted by a sudden increase in digit volume on the plethysmographic tracings. If the gradient between any two successive levels exceeds 20 to 30 mm. Hg, an arterial occlusion exists between these points.*

Segmental pressures provide information to: 1) localize occlusions; 2) provide dynamic data

* This method is accurate in localizing the level or levels of occlusion in about 85 per cent of cases.[18]

TABLE 1. *Level of Palpable Pulses of Patients in Study*

	Subjectively Improved	Not Improved
Pedal pulses, one or both	3	1
Popliteal, none below	0	1
Femoral, none below	7	18
No palpable pulses	4	5
Total	14	25

* Submitted for publication December 2, 1963.

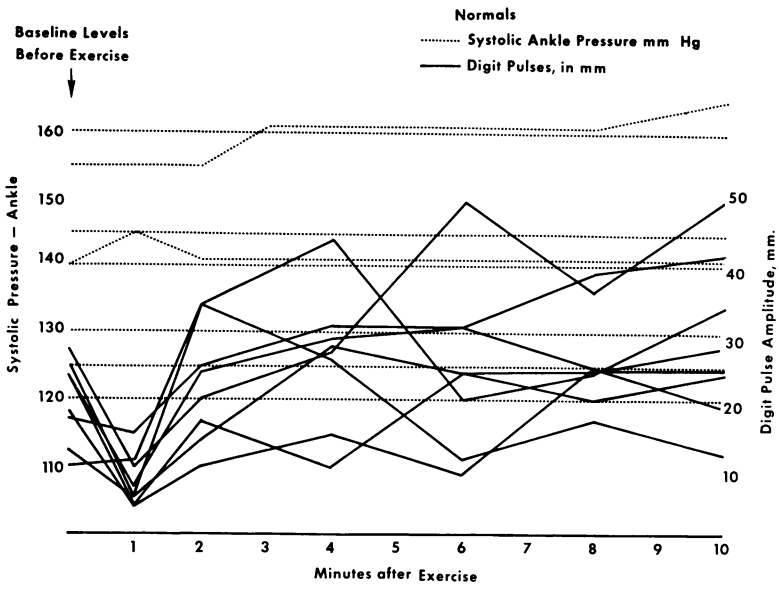

FIG. 1. Five minutes of treadmill exercise normally results in no change in the ankle pressure and a transient decrease in the digit pulse amplitude (skin flow).

as to the extent of the pressure drop across the occluded areas; and 3) compare over long-term follow up the changes in distal arterial pressure that occcur with sympathectomy.

2. *Digit Volume Pulse Studies:* When the mercury strain-gauge is placed about the terminal digit, volume changes in the digit occur with each heart beat. These changes are recorded and measured in mm. of deflection. As Burton [3] has shown there is an excellent correlation between the volume pulse amplitude and digit blood flow. After obtaining baseline digit pulses, the distal extremity is subjected to a vasodilating stimulus, the reactive hyperemia test, comparing the pulse volume response to the baseline control. The reactive hyperemia test consists of five minutes of arterial occlusion by a pneumatic cuff on the ankle. With release of the occlusion, there is an increase in the digit pulse amplitude which is a sensitive index of the increase in flow which has occurred. These tests are repeated on all patients pre- and postoperatively.

These digit volume pulse studies give information to 1) establish baseline pulse volume data; 2) correlate the observed responses with those seen after sympathectomy; and 3) establish the correlation between observations made on the distal extremity and claudication.

3. *Level of Sympathetic Activity and Return in Tone:* Normally with deep inspiration there is a reflex transient peripheral vasoconstriction manifested by a decrease in digit pulse amplitude. The reflex vasoconstriction is a manifestation of an intact functional sympathetic chain. Disappearance of this reflex may be used to determine completeness of sympathectomy. Likewise the response to reactive hyperemia was used as an indicator of return in tone. If a marked increase in the digit pulse amplitude occurs after five minutes of arterial occlusion, sympathectomy was either incomplete or regeneration has occurred.

4. *Exercise Studies:* Beginning in 1962, all patients with claudication who were being considered for sympathectomy and all those returning for follow up were subjected to treadmill exercise at 1.7 mph on a 10 per cent grade. Prior to and immediately after the period of exercise the patients were studied in the supine position, determining both the digit volume pulses and systolic ankle pressures. Exercise was carried out until they were unable to walk any longer because of pain. The normal response to exercise is shown in Figure 1. The ankle pressures remain unchanged but the digit pulses may transiently decrease in volume, followed rapidly by a more prolonged rise before returning to the baseline.

In patients with occlusive arterial disease and claudication, the response is entirely different (Fig. 2). Often both the ankle pressures and the digit pulses drop to unrecordable levels. These two parameters then very slowly return to the baseline, occasionally requiring up to 20 minutes.

Of the 39 extremities subjected to lumbar sympathectomy for claudication, 23 had exercise tests on the treadmill after the procedure. Eight of this group had tests before and after the procedure.

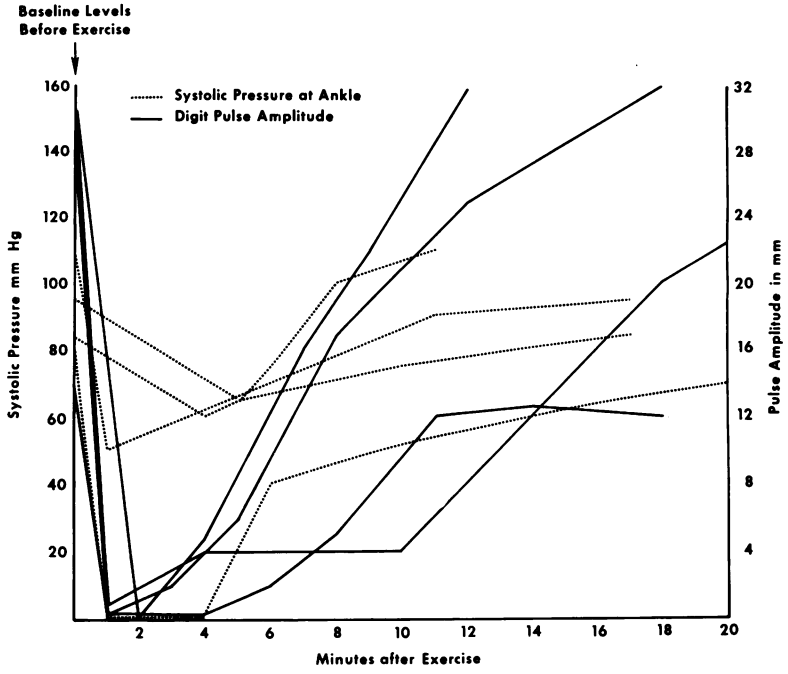

FIG. 2. With occlusive arterial disease, the systolic ankle pressures recorded after exercise decrease occasionally to unrecordable levels requiring several minutes to return to pre-exercise levels. The changes in digit blood flow follow a similar pattern.

Results

Eleven patients in this current study (38%) stated they were improved and the remaining 18 (62%) stated they were unimproved. A complete evaluation of these two groups is as follows:

Unimproved Group: (18 Patients)

1. Ankle pressure changes: Twelve extremities had no change or a slight decrease. Four increased only slightly (10–20 mm. Hg). However, nine had an increase greater than 20 mm. Hg. In this group two had concomitant rises in arm pressure to account for the change.

2. Changes in digit pulse amplitude: Ten of the denervated extremities had a greater than tenfold increase in digit pulse amplitude while nine had a two to tenfold increase. Six had no change during follow up.

3. Return in sympathetic tone: Twenty showed no return in sympathetic activity while five had a definite return in vasomotor tone.

4. Exercise studies: None of the unimproved patients tested in this group had either a normal response to exercise or an improvement in their post exercise response. All had a drop in ankle pressure and marked decrease in digit pulse amplitude.

Comment: From these objective studies we are unable to determine any correlation whatsoever between the subjective lack of improvement and objective data that showed increases in distal arterial pressure and digit blood flow. The one consistent finding in this group was the abnormal exercise response which was unaffected by the sympathectomy.

Improved Group: (11 Patients)

1. Ankle pressure changes: Only two extremities in this group had a greater than 20 mm. Hg rise in pressure and in both cases this was accompanied by a corresponding rise in arm pressure.

2. Digit pulse amplitude: Eight of the extremities had a greater than twofold increase in amplitude. The remaining six had no change or a decrease.

3. Return in sympathetic tone: Seven extremities were completely denervated with no return in tone. The remaining seven exhibited a definite return in sympathetic activity.

Since a critical evaluation of those patients claiming improvement is essential to this discussion, they will be presented in detail:

Case 1: 66-year-old white man with a two-year history of right calf claudication at one-half block of walking. The right femoral artery pulse was the only palpable pulse and was normal. A right femoral arteriogram showed a superficial femoral artery occlusion. Preoperatively his ankle pressure was 80 mm. Hg with a digit pulse amplitude of 1 mm. He was forced to stop on the treadmill in three and one-half minutes with a drop in the ankle pressure to 50 mm. Hg. Digit pulses were unrecordable for greater than five minutes. Sixteen months after a right sympathectomy he stated his walking distance was now two blocks. The ankle pressure remained unchanged but the digit pulse amplitude had increased to 18 mm. On the treadmill he was forced to stop in four minutes and ankle pressures and digit pulses were unrecordable after exercise. His sympathectomy appears to have been complete.

Comment: On closer questioning the patient stated he was walking slower. On the treadmill he walked 30 seconds longer with a more abnormal exercise response than was seen at the time of preoperative evaluation. A 30-second change in walking time is not significant in our experience. This patient is considered unchanged.

Case 2: 61-year-old white man with left hip and calf claudication brought on by one to three blocks of walking. All pulses were palpable except for an absent posterior tibial pulse. Seven months after a left sympathectomy the patient stated his walking distance had increased to four to five blocks. The ankle pressure was unchanged but digit pulse amplitude had increased from five to 46 mm. There was definite evidence of residual sympathetic activity. On the treadmill he developed hip pain in 60 seconds and calf pain in 100 seconds. There was a decrease in digit pulse amplitude but ankle pressure remained unchanged.

Comment: This patient was stopped by his hip pain before having to stop for calf pain so the exercise response is probably misleading. We seriously doubt that the L_2-L_4 sympathectomy can be given credit for relief of hip pain which occurred in 60 seconds on the treadmill. It is of interest that he was incompletely denervated. We consider him as unimproved.

Case 3: 60-year-old white man had undergone left sympathectomy for one block claudication four years previously. He stated that his walking distance had increased to five blocks. The left ankle pressure was 90 mm. Hg and remained unchanged during our follow-up period. He exhibited a considerable degree of sympathetic tone after his sympathectomy with toe pulse amplitude increasing from 13 to 25 mm. after reactive hyperemia. Since he had calf claudication on the right his left leg was exercised with a foot ergograph. Calf pain developed in three minutes, 15 seconds and resulted in a decrease in ankle pressure from 90 to 60 mm. Hg and digit pulse amplitude from 14 to 1 mm.

Comment: With the definite development of calf claudication and abnormal response to exercise the patient is considered as questionably improved. If he is improved it is in the face of marked residual vasomotor tone.

Case 4: 52-year-old white man with a three-year history of one-half to one block bilateral calf claudication. All pulses absent on the right, only a weak femoral pulse on the left. By angiography the patient had a right common iliac occlusion, left external iliac stenosis and bilateral superficial femoral occlusions. Bilateral lumbar sympathectomy was carried out. Ankle pressures decreased postoperatively coinciding with a drop in arm pressure. The digit pulse amplitude remained unchanged. There was no evidence of regain in sympathetic tone. On the treadmill he developed calf pain on the left in one minute, 15 seconds and on the right in 100 seconds.

Comment: Although he may be improved, this short walking time represents severe claudication. He is considered improved.

Case 5: 65-year-old white man in 1956 had a left lumbar sympathectomy which the patient stated cured his claudication. Four years later he developed right calf claudication after walking one block. There were no palpable pulses on the left and a weak femoral pulse on the right. Exercise on the treadmill produced right calf pain in two minutes, 15 seconds. The ankle pressures and toe pulses were unrecordable after exercise. Even though the right calf pain stopped him before he developed left calf complaints, his left ankle pressure decreased from 90 to 35 mm. Hg and toe pulses disappeared. Eight months after right sympathectomy his right calf pain occurred in the same time as preoperatively with the same response. His ankle pressure and digit pulses remained unchanged.

Comment: There was no objective improvement on the right which was completely denervated. The patient had considerable vasomotor activity on the improved side with an increase in the digit pulse amplitude of 15 to 25 mm. after reactive hyperemia. The patient has to be considered improved on the left since we have no objective evidence to the contrary.

Case 6: 73-year-old white man with a three-year history of right calf claudication with one block. He had a palpable femoral artery pulse on the right but none distally. Preoperatively he was able to walk for one minute, 45 seconds on the treadmill. Ankle pressure and toe pulses were unrecordable after exercise. Three months after right lumbar sympathectomy ankle pressure had decreased from 85 to 60 mm. Hg. Although walking time was 60 seconds longer postoperative, he experienced very severe calf pain and it required 20 minutes for ankle pressure and digit pulses to return to baseline. This physiologic response was one of the most abnormal we have seen and was not modified by the procedure.

Comment: Claudication the patient experienced on the treadmill was more severe than that he had preoperatively. He apparently pushed himself and hence walked farther. In view of the severity of his pain, and the physiologic response, we consider him unimproved.

Case 7: 64-year-old white man with a one-year history of left calf claudication walking less than one block. He had a normal femoral artery pulse on the left but none distally. Left femoral arteriogram showed a superficial femoral artery occlusion with plaquing in the popliteal. Ten months after sympathectomy his digit pulse amplitude increased from 4 to 20 mm. Hg. His ankle pressure had increased from 90 to 140 mm. Hg coinciding with a 40 mm. Hg increase in arm pressure. The patient stated he had no claudication at this time. When placed on the treadmill he was forced to stop in 45 seconds because of marked shortness of breath.

Comment: The reason the patient could not experience claudication was because of cardiorespiratory difficulties which markedly reduced his activity. Even with only 45 seconds on the treadmill, he had a decrease of 30 mm. Hg in ankle pressure and digit pulses from 20 to 4 mm. He is considered questionably improved.

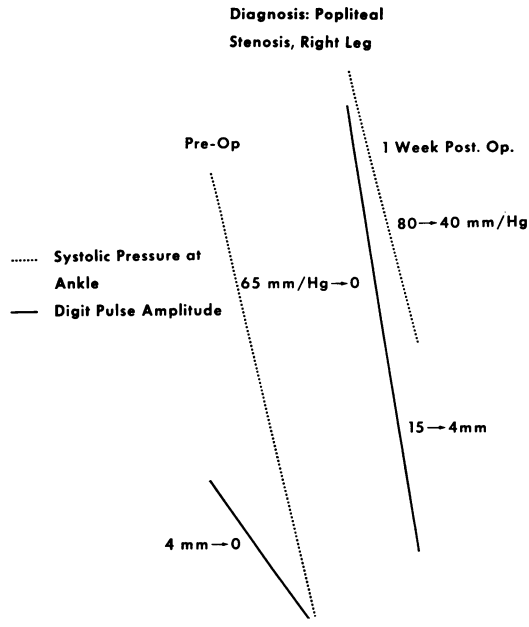

FIG. 3. Preoperatively the patient walked three minutes on the treadmill before he developed claudication. One week postoperatively the walking time had increased to five minutes with a modified response which was still grossly abnormal.

Case 8: 46-year-old white man with a two-year history of one block claudication of right calf. He had a normal femoral artery pulse but none below this level. Femoral arteriogram showed marked stenosis of the proximal popliteal artery. Preoperatively he walked for three minutes on the treadmill. One week after lumbar sympathectomy digit pulse amplitude increased from 4 to 35 mm. and ankle pressure increased from 65 to 80 mm. Hg. At this time he walked for five minutes on the treadmill developing only minimal claudication. The response to exercise was modified considerably but remained abnormal (Fig. 3).

Comment: There seems to be no question that sympathectomy modified the response to exercise. Whether this will be maintained is conjectural since the patient was lost to follow up. He is considered improved.

Case 9: 49-year-old white man with a two-year history of bilateral calf claudication starting in three to four blocks. He was found by arterio-

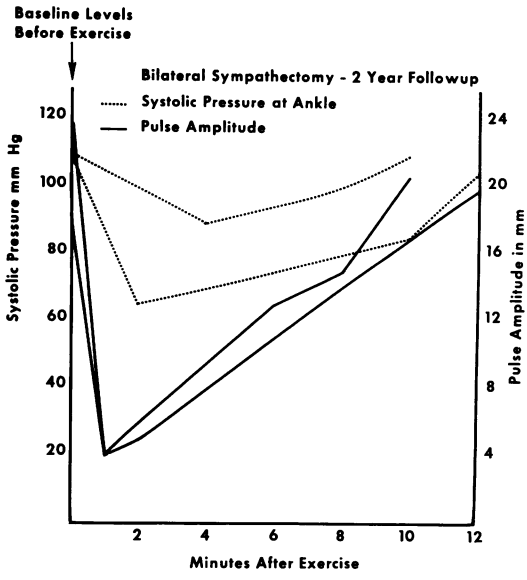

FIG. 4. The pressure drop although not too great required 10–12 minutes to return to the pre-exercise level. The digit pulse amplitude decrease was grossly abnormal.

graphic and segmental pressure studies to have a right iliac stenosis and left superficial femoral artery stenosis. Two years postoperative the patient claimed a miraculous cure, stating that he could walk for one-half mile without symptoms. Although his sympathectomies were done prior to our exercise studies, he was able to walk for five minutes on the treadmill without pain. His response to exercise (Fig. 4) was abnormal but not as severe as usually seen. In addition he had evidence of return in sympathetic activity with a rather marked increase in digit pulse amplitude following the reactive hyperemia test.

Comment: This patient might be considered a dramatic result if it were not for the fact that on closer questioning it was noted that he had gone on a self-imposed diet and lost a total of 30 pounds. As Hillestad[7] has shown, weight can profoundly affect walking distance. He is considered questionably improved by sympathectomy.

Case 10: 39-year-old white man with a three-year history of right calf claudication after walking one block. Bilateral femoral artery pulses were the only palpable pulses in the lower extremities. Right femoral arteriogram revealed narrowing of the popliteal artery without occlusion. The first exercise test was carried out one and one-half years after a right lumbar sympathectomy and the results are shown in Figure 5. The only abnormality seen after five minutes of painless walking is the decrease in the digit pulse of the operated side but without a change in the ankle pressure.

Comment: This is the only patient in this series whose ankle pressure rose after the exercise period. Since preoperative exercise was not done at the time of sympathectomy, he must be listed as improved.

Case 11: 66-year-old white man noted bilateral calf claudication—left greater than right at one block—nine months prior to admission. Femoral artery pulses were palpable bilaterally, with all pulses distal to this being absent. One year after left sympathectomy the patient stated he was greatly improved and was able to walk seven minutes on the treadmill before calf pain developed. The right leg was also greatly improved without any therapy. At 18 months claudication distance was six blocks, left being more symptomatic than the right.

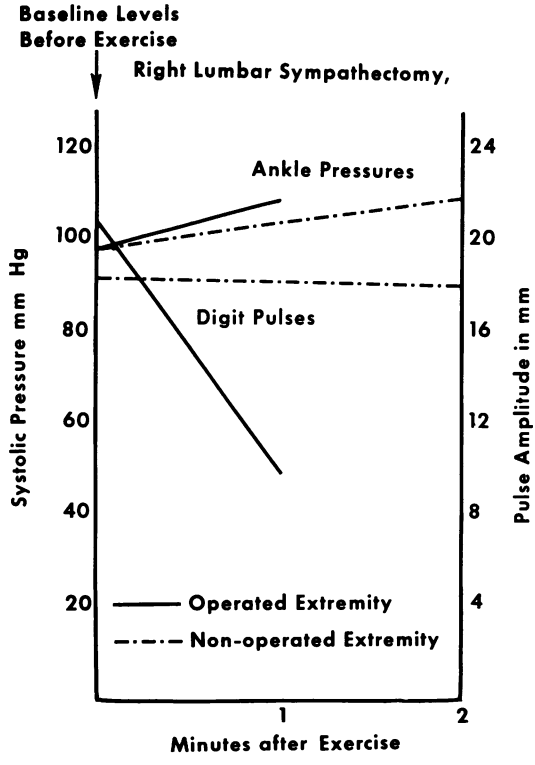

FIG. 5. This illustrates the response to exercise of Case 10.

Comment: Coinciding with this dramatic improvement, there was a rise in ankle pressures bilaterally. The left ankle pressure went from 60 mm. Hg in 1961 to 105 mm. Hg in 1963. The right ankle pressure went from a low of 80 mm. Hg in 1961 to 105 mm. Hg in 1963. During this period the patient's arm systolic pressure went from 180 to 210 mm. Hg. It seems logical to ascribe the patient's improvement to an increase in central pressure which in turn increased pressures below the obstructions, thus improving driving pressure to exercising muscles. We doubt seriously that the sympathectomy can be given credit for this improvement, particularly when the non-operated side showed similar improvement.

Discussion

Using all the parameters mentioned in this study, we consider that only four (five sympathectomies) of the 11 patients claiming improvement appeared to derive real benefit from sympathectomy. The remaining seven had no real objective signs of improvement or were very doubtfully improved. Two of four in whom improvement seemed to be certain had definite return of sympathetic activity. If the postoperative exercise studies on the 23 tested extremities are evaluated (Fig. 6, 7), only two had a normal pressure response and only one had a normal digit pulse response. This makes it very unlikely that lumbar sympathectomy alters the physiologic response to calf muscle ischemia.

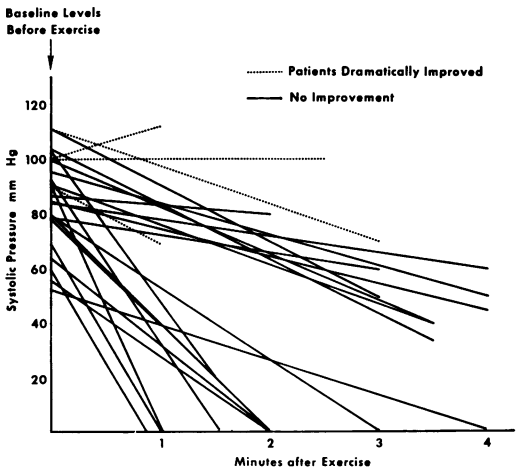

FIG. 6. The systolic pressures shown represent single determinations before and after exercise at the times indicated. In all but two instances the ankle pressure decreased following exercise.

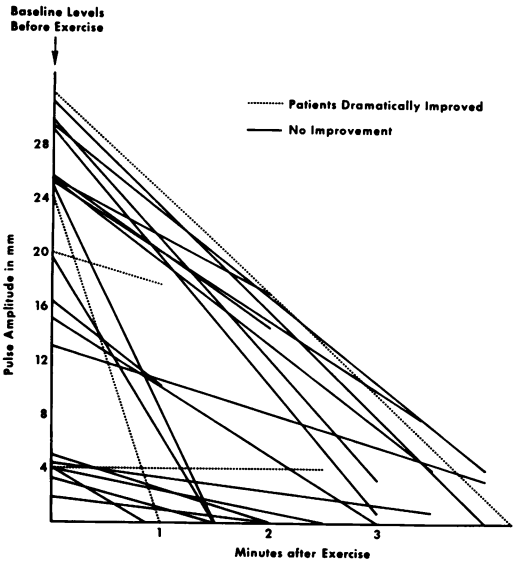

FIG. 7. The digit pulse amplitudes shown before and after exercise represent single plots at the times indicated. Only one patient exhibited a normal response.

It is obvious from this study that subjective evaluation by the patient is not an adequate index of the procedure's effect. Since only four of our patients demonstrated evidence of improvement, the question of selection arises. According to Smithwick,[16] this is very important if one is to achieve good results with this operation. He utilized plethysmographic technics in a constant temperature room and then correlated these findings with clinical estimates of collaterals and levels of occlusion. He concluded that the more distal the disease and the more responsive the vessels to cold, the better the expected response. Our results are in contrast to his in that, of the extremities denervated in the unimproved group, 19 had a greater than twofold increase in peripheral blood flow yet

failed to achieve satisfactory results. It is doubtful whether or not changes in the acral circulation can be used to estimate potential changes in the deep arterial circulation. These changes in digit blood flow correlate poorly with the observed response.

It is our opinion that certain basic questions require an answer before lumbar sympathectomy can be accepted as a satisfactory procedure for treatment of claudication.

Does sympathectomy increase muscle blood flow? The denervation does produce a reduction in vasoconstrictor tone in skeletal muscle but when compared to the skin response, there are important differences. Barcroft and Swan [1] have shown that both skin and muscle blood flow do increase after sympathectomy. With muscle flow the maximum is attained sooner (about two days); its extent is smaller and the regain in intrinsic tone is quicker, requiring about eight days. After this period the resting level of flow is only slightly above the pre-sympathectomy level.

Is the vasodilatation produced by sympathectomy greater than that which results from exercise itself? From the results of the exercise tests in those patients with sympathectomy (Fig. 6, 7), the answer is obviously no. Decrease in resistance in the exercising muscle is so profound that distal extremity blood flow is shunted to the ischemic muscle. If sympathectomy were effective in producing a significant persistent increase in skeletal muscle flow, *sufficient* to prevent claudication, this shunting should not occur.

Does the decrease in vascular resistance persist? As Simeone [14] has pointed out, "The result of sympathectomy is never again as great as it is on the first day or two after operation." This has important implications because if true, it means that the greatest benefit in terms of blood flow should occur during the first week or so after denervation. In our series 12 of the 39 denervated extremities showed definite return in vasomotor tone. Whether this represents incomplete denervation initially or regeneration of sympathetic fibers is unknown.

Does sympathectomy decrease collateral resistance? We do not believe this has been objectively or experimentally verified and this is probably the most important single consideration. If sympathectomy could effectively reduce collateral resistance and decrease pressure drop across these vessels, thus effectively raise perfusion pressure of the exercising muscle, claudication might be benefitted. In the unimproved group seven extremities had a >20 mm. Hg rise in ankle pressure without a corresponding rise in arm pressure. In the improved group no patient had a rise in ankle pressure without a change in arm pressure. There was no consistent change in ankle pressues in the sympathectomized extremities to indicate that collateral resistance was significantly reduced.

Does sympathectomy reverse the physiologic response of the ischemic extremity to exercise? Since only two patients had what might be considered a normal response, the answer must be, rarely. In one of these patients improvement occurred in the non-sympathectomized leg as well so the operation cannot be given credit for this. Whether or not it will modify the response to any significant degree cannot be answered for certain at this time.

If future studies are to be carried out, the individual patient's physiologic response to exercise appears to hold great promise. In this situation the patient serves as his own control since any effect sympathectomy has on improving claudication must modify this response or be considered a failure. It appears that a study of this sort should include the following:

1. Baseline study of arm pressures and finger pulses with ankle pressures and toe pulses.
2. Exercise to point of claudication.
3. Minute-to-minute recordings of ankle pressures and digit pulses such as shown in Figures

1 and 2. This would not only establish the magnitude of the pressure and pulse decrease, but also would establish the amount of time required to return to baseline levels.

4. These same studies should then be repeated during the first week or two after sympathectomy, then every six months.

It is our contention that this will provide objective, physiologic data which require very little in the way of subjective evaluation. If sympathectomy improves claudication, then it should modify the physiologic response to exercise.

Summary and Conclusions

A critical objective evaluation of the results of lumbar sympathectomy has been presented. The patients were evaluated by digit plethysmographic technics pre- and postoperatively with the following results:

There is no correlation between observed changes in digit blood flow and clinical results.

Definite return in sympathetic tone occurred in 12 of 39 denervated legs. There was likewise no correlation between return in activity and results.

With exercise to the point of claudication. there is a marked drop in digit blood flow and ankle pressure often to unrecordable levels. This abnormal response to exercise is not reversed by lumbar sympathectomy.

Only five (13%) of the 39 extremities denervated experienced any significant improvement in claudication.

The physiologic response to exercise holds great promise as an objective test in evaluating the results of lumbar sympathectomy.

References

1. Barcroft, H. and H. J. C. Swan: Sympathetic Control of Human Blood Vessels. Williams & Wilkins Co., 1953, p. 64.
2. Blain, A. III, A. T. Zadeh, M. L. Teves and R. J. Bing: Lumbar Sympathectomy for Arteriosclerosis Obliterans. Surgery, **53**:164, 1963.
3. Burton, A. C.: The Range and Variability of the Blood Flow in Human Fingers and the Vasomotor Regulation of Body Temperature. Amer. J. Physiol., **127**:437, 1939.
4. DeBakey, M. E., O. Creech and J. P. Woodhall: Evaluation of Sympathectomy in Arteriosclerotic Peripheral Vascular Disease. J.A.M.A., **144**:1227, 1950.
5. Gibbons, G. E., D. E. Strandness, Jr. and J. W. Bell: Improvements in Design of the Mercury Strain Gauge Plethysmograph. Surg. Gynec. & Obstet., **116**:679, 1963.
6. Gillespie, J. A.: Future Place of Lumbar Sympathectomy in Obliterative Vascular Disease of Lower Limbs. Brit. Med. J., **2**:1640, 1960.
7. Hillestad, L. K.: The Blood Flow in Intermittent Claudication, IV. Acta Med. Scand., **173**:467, 1963.
8. Listerud, M. B. and H. N. Harkins: A Clinical Analysis of Experiences with Lumbar Sympathectomy at the King County Hospital, 1948–1955. West. J. Surg., **74**:189, 1956.
9. Luke, J. L.: The Value of Lumbar Sympathectomy in Intermittent Claudication. Surgery, **41**:165, 1957.
10. Mackenzie, D. C. and J. Lowenthal: Lumbar Sympathectomy and Claudication Distance. Surg. Gynec. & Obstet., **115**:303, 1962.
11. Mavor, G. E.: Intermittent Claudication and Sympathectomy. The Lancet, **2**:794, 1955.
12. Palumbo, L. T. and D. J. Lulu: Lumbar Sympathectomy in Peripheral Vascular Diseases. Arch. Surg., **86**:512, 1963.
13. Roman, M., C. W. Robertson and P. Cooper: End Results of Lumbar Sympathectomy for Peripheral Obliterative Arteriosclerosis. Surgery, **40**:857, 1956.
14. Simeone, F. A.: Intravascular Pressure, Vascular Tone and Sympathectomy. Surgery, **53**:1, 1953.
15. Smith, R. G., M. Gullickson and D. A. Campbell: Some Limitations of Lumbar Sympathectomy in Arteriosclerosis Obliterans. Arch. Surg., **64**:103, 1952.
16. Smithwick, R. H.: Lumbar Sympathectomy in the Treatment of Obliterative Vascular Disease of the Lower Extremities. Surgery, **42**: 415, 567, 1957.
17. Strandness, D. E., Jr., G. E. Tolstedt, and J. W. Bell: Results of Combined Surgical Therapy in Management of Peripheral Arterial Disease. Arch. Surg., **81**:649, 1960.
18. Strandness, D. E., Jr., H. M. Radke and J. W. Bell: Use of a New Simplified Plethysmograph in the Clinical Evaluation of Patients with Arteriosclerosis Obliterans. Surg. Gynec. & Obstet., **112**:751, 1961.