THE CARE AND REHABILITATION OF PATIENTS
WITH INJURIES OF THE SPINAL CORD AND CAUDA EQUINA
A PRELIMINARY REPORT ON 113 CASES
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ONE of the most distressing and laborious experiences in medicine is the care of patients with spinal cord injury. We have had to face the difficult problem of caring for large numbers of these patients because of the almost miraculous effects of sulfonamides, penicillin, and streptomycin. The efficiency of the Army Medical Department, increased by placing skilled surgeons near the front lines in battle, and the rapidity and ease of evacuation by air of the wounded have added to the scope of our problem by increasing the total number of these patients.

During World War I, fully 80 per cent of the men who received an injury to the spinal cord failed to return to this country. However, through the rapid strides made in medicine, speedy evacuation of the wounded and the persistence of young medical officers who refused to accept the attitude expressed by some that these cases were hopeless, today large numbers of patients with spinal cord injury have been returned to this country and are now living. The total number of cases in Army General Hospitals on V-J Day has been estimated at approximately 1200 to 1400.10 This is a challenge that cannot be ignored.

During the past twelve months the care and rehabilitation of these patients has advanced more than in the previous three years of War, while those three years of the War brought forth more information than the preceding thirty years. Thus we may say that our understanding of traumatic injuries to the spinal cord has advanced in a geometrical progression.

HISTORICAL NOTE

Tracing this line of geometrical progression as described by Courville,1 we first find mention of the spinal cord about 400 B.C. by Hippocrates. Celsius in the 1st Century A.D. and Aretaeus in the 2nd Century A.D. also made references to functions of the spinal cord. The earliest known reference to traumatic lesions of the spinal cord is found in the Edwin Smith surgical papyrus,7 in which six cases of injury to the cervical spine, with the characteristic dislocation, displacement, and crushing of the vertebrae, were presented. In addition to the gross lesion of the spine itself, paralysis of all four extremities, urinary incontinence, priapism and involuntary

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ejaculation of semen were described. Beyond this unusual surgical document, nothing of note on the subject was recorded until Galen, 1st Century A.D., conducted experiments on the effects of trauma to the spinal cord. He found, for example, that a longitudinal slit in the cord failed to disturb function to any serious degree, while transverse section of the cord at various levels produced paralysis of the area below the segment. The significance of this work of Galen seemed lost on medieval surgeons, who believed the spinal cord was comparable to the marrow of any other long bone. Operations for fractures of the spine were first advised by Paulus Aegineta in the 7th Century, but this suggestion was ignored until several hundred years later when Fabricius Hildanus in 1545 again referred to the advisability of surgery in such cases. However, M. Louis (1774) actually undertook the first operation for this condition. It is of historical interest that the surgeons of this period were much more concerned with the bony lesion than they were with any injury of the spinal cord or of its various nerve roots.

The matter of gunshot wounds of the spine and spinal cord was brought to light during the American Civil War. In the Medical and Surgical History of the War of the Rebellion are found reports of 642 such cases of gunshot wounds, or 0.25 per cent of the total number of wounds recorded therein. The approximate percentage of such spinal cord injuries in World War II was 0.234 per cent.

War is without doubt the largest single contributing factor to the study of injuries to the spinal cord. Frazier and Allen8 in 1918, in their monograph Surgery of the Spine and Spinal Cord, gave a good general survey of the effects of spinal cord injury. However, their studies were limited to a much smaller number of patients who survived transportation to this country from Europe than have been returned to this country from all parts of the globe following cessation of hostilities in World War II. After World War I, approximately 20 per cent of all patients who had spinal cord injury were evacuated to this continent successfully, but only 10 per cent of these survived the first year. It is estimated that there is less than 1 per cent now living of the group on which studies were made. But modern advances in medicine and in transportation have been so great in the years intervening between the close of World War I and World War II, it is of the utmost importance for those future victims of transverse myelitis, due either to war or to peace-time accidents, that every effort be made to erase the ancient and medieval concepts, prevalent even today, that these cases are hopeless and helpless. One writer has expressed the despairing attitude thus:

It is a matter of preserving life by constant and meticulous care when life is of little value to the patient [italics are author's] and costly to his relatives. . . . And not infrequently some surgeon can be persuaded by the importunate family to explore. In such a case the physician is relieved of his distressing duty.1

CARE OF SPINAL CORD INJURIES

The purpose of this preliminary report is to review the progress in the care and rehabilitation of 113 patients with traumatic spinal cord lesions.
The total number of patients seen was 132, but 19 were not observed for the continuous period of 18 months and hence are not included in the report. It is the conviction of the writer, arrived at as a result of his experience in dealing with over a hundred cases, that the patient with a traumatic spinal cord injury, in the greater majority of cases, is not one to be considered hopeless, helpless and incapable of earning a livelihood. In fact, our cases have shown most gratifying results. These patients can earn a living and become virtually independent.

**TABLE 1**

*Statistical summary of spinal cord injuries*

<table>
<thead>
<tr>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete</td>
<td>80</td>
</tr>
<tr>
<td>Anatomical</td>
<td>62</td>
</tr>
<tr>
<td>Physiological</td>
<td>18</td>
</tr>
<tr>
<td>Incomplete</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>113</td>
</tr>
<tr>
<td>Cervical (All cervical vertebrae levels between C-3 to C-7)</td>
<td>10</td>
</tr>
<tr>
<td>Upper dorsal (T-1 to T-6 vertebral level)</td>
<td>25</td>
</tr>
<tr>
<td>Lower dorsal (T-7 to L-1 vertebral level)</td>
<td>46</td>
</tr>
<tr>
<td>Cauda equina (L-1 to S-4 vertebral levels)</td>
<td>32</td>
</tr>
<tr>
<td>Total</td>
<td>113</td>
</tr>
<tr>
<td>Injury caused by: A) Shell fragments.</td>
<td>50</td>
</tr>
<tr>
<td>B) Bullets</td>
<td>40</td>
</tr>
<tr>
<td>C) Fractures of vertebra</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>113</td>
</tr>
<tr>
<td>Laminectomies</td>
<td>79</td>
</tr>
<tr>
<td>Suprapubic cystotomies</td>
<td>89</td>
</tr>
<tr>
<td>Perineal cystotomies</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>92</td>
</tr>
<tr>
<td>Cordotomies</td>
<td>10</td>
</tr>
<tr>
<td>Sympathectomies</td>
<td>1</td>
</tr>
<tr>
<td>Transurethral resections</td>
<td>2</td>
</tr>
<tr>
<td>Alcohol injection 3rd sacral root, unilateral</td>
<td>1</td>
</tr>
<tr>
<td>Deaths (pyelonephritis, 3; acute hepatitis, 1)</td>
<td>4</td>
</tr>
</tbody>
</table>

The treatment of the patient immediately after injury has been adequately described by previous writers and hence needs no repetition here. The scope of this paper is to deal with the care of the patient during two phases: the bed-ridden phase and the ambulatory phase.

**I. BED-RIDDEN PHASE**

The care of the patient in the bed-ridden phase can be divided into (1) care of the bladder; (2) care of the bowels; (3) care of decubitus ulcers; (4) maintenance of nutrition; (5) control of pain; (6) control of spasm; (7) physiotherapy.
1. CARE OF THE BLADDER

In the patient afflicted with an injury of the spinal cord, retention of urine is almost always a constant complication. This complication arises within a short time after the initial injury to the spinal cord and is ever present until recovery from the injury ensues or until the bladder regains some of its function and a so-called "automatic bladder" is established. The immediate problem is to relieve the distention so as to prevent reflux infection of the bladder, ureters, and kidneys themselves.

In war-time practice it has been feasible to perform suprapubic cystotomies rather than to use in-dwelling catheters. Many doctors in civilian practice have raised the question of the expediency of this procedure. Suprapubic cystotomies were employed in battle casualties rather than in-dwelling catheters primarily because of the constant changes of personnel attending these patients as they were evacuated to the rear and finally to this country. A suprapubic cystotomy was much more practicable in the transfer of a patient from ambulance to plane to boat than the in-dwelling clamped-off catheter, which could easily be overlooked. The suprapubic cystotomy is too obvious to miss, the personnel handling these patients are soon accustomed to looking for it, and the patient is more keenly aware of its presence and can call attention to it. An in-dwelling catheter would accomplish the same result but the opportunities for causing the very thing we wish to avoid—bladder distention—are immeasurably greater.

Once the patient arrived at a permanent station, the practice of removing the suprapubic tube, inserting a urethral catheter (Foley type) and establishing tidal drainage was instituted. Here the definitive treatment may be said to begin.

Of the 113 patients in this series (see Table 1), 89 had suprapubic cystotomies performed and 3 had perineal cystotomies. Approximately 90 per cent of these cystotomies were done at time of exploratory laminotomies by simply turning the patient over and performing the operation without anesthesia since, in all instances, the sensory level was well above the site of election for the cystotomy. While caring for these patients over a period of 19 months, two major facts became evident to the writer.

First, the site of election for performing a suprapubic cystotomy changed from just above the pubis to a point well up on the dome of the bladder. This has been a decided factor in allowing spontaneous healing of the fistula following removal of the suprapubic tube. Those cystotomies that were done near the pubis failed to close and necessitated closure and surgical revision as any other sinus in the body. The cystotomies performed at the dome of the bladder almost invariably closed spontaneously within 3 days after removing the tube and inserting urethral catheter without tidal drainage. They were healed firmly enough in 3 weeks to allow either tidal drainage or a trial at automatic voiding.

Secondly, the perineal cystotomy has proved to be of great hindrance in permitting the patient to develop an automatic bladder. It readily allowed
kinking of the catheter which was followed by seepage of urine about the catheter and damage to decubiti because of undetected wetting of sheets. When the perineal cystotomy catheter was removed the fistula failed to heal and in each of the 3 cases of perineal cystotomy, plastic surgery had to be resorted to with much difficulty. In addition, the patients were forced to remain in bed and thus lost much valuable time in their rehabilitation.

**Tidal Drainage**

Following the precepts of Munro, who in 1934 described a method of irrigation and development of automatic bladder in such cases, a modified form of tidal drainage apparatus was installed on the ward housing these patients. The almost immediate drop from temperature elevations so common when these patients were previously on manual catheter irrigation was stimulating. The apparatus employed was used because of its simplicity in construction and maintenance. It also permitted the patient to wash out completely his own bladder at frequent intervals by application of clamps on the tubing. Patients were encouraged to participate in ambulation and outdoor activities in wheel-chairs in spite of their being on catheter drainage. The simplicity of the arrangement made this possible. Many do not agree with the principle of allowing patients with catheters to remain out of bed for long periods of time. However, if these patients are to be kept alive and well long enough to accomplish results, it is of paramount importance that they begin to become ambulatory as early as possible. Consideration, of course, must be given to degree of damage to vertebral structures. If union of vertebral bodies is sufficient, the patient is allowed up in wheelchair after 4 months.

Solutions of boric acid (1:500) alternating weekly with acetic acid (0.5 per cent) were used. It has been our experience that the acetic acid aided in "cutting" the mucus formed around the catheter. A Foley catheter F.18 was used and changed every 7 days unless encrustations occurred prior to that time. Solution M. and Solution G. were found to be too irritating and their use was discontinued for routine irrigation.

**TABLE 2**

<table>
<thead>
<tr>
<th>Vertebral Level of Injury</th>
<th>On Catheter Drainage</th>
<th>Automatic Bladder</th>
<th>Normal Bladder</th>
<th>Total No. Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical (C-3 to C-7)</td>
<td>1</td>
<td>6</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Thoracic (T-1 to T-6)</td>
<td>3</td>
<td>20</td>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>Thoracic (T-7 to L-1)</td>
<td>2</td>
<td>38</td>
<td>6</td>
<td>46</td>
</tr>
<tr>
<td>Cauda equina (L-2 to S-4)</td>
<td>0</td>
<td>23</td>
<td>9</td>
<td>32</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td>87</td>
<td>29</td>
<td>118</td>
</tr>
<tr>
<td>Percentage</td>
<td>5.3%</td>
<td>77%</td>
<td>17.7%</td>
<td>94.7%*</td>
</tr>
</tbody>
</table>

* Percentage of total number of patients without catheter drainage.
From Table 2 it can be seen that there is no apparent correlation between the site of injury to the spinal cord and the development of automaticity. The development of a normal bladder control with normal sensation can only be explained by the fact that these patients had incomplete lesions of spinal cord itself or of the cauda equina. Table 2 also shows the value of using tidal drainage on the patient with a spinal cord injury. Some urologists feel that tidal drainage is sufficient for irrigation of the bladder but not necessary for establishing bladder capacity nor rehabilitation of the paralyzed bladder. On the contrary, in our experience with large groups of patients, we have found tidal drainage indispensable for the attainment of a "social bladder." Without this method we would not have been able to care for this large group of patients efficiently.

**Treatment of Urinary Infections**

Repeated urine cultures revealed the following organisms to be present most frequently as pure cultures: *Aerobacter aerogenes*, *Escherichia coli*, and *Bacillus proteus* in the order given.

The following organisms were found to be present in combinations most frequently: *E. coli* and *A. aerogenes*, and *E. coli* and *Streptococcus non-haemolyticus*. Penicillin and sulfonamides have been effective in combating the gram-positive group but their effects were not of long duration due to the persistence of the gram-negative organisms. Combined courses of streptomycin and penicillin gave good results. Sulfonamides were used as little as possible because of the great tolerance developed by these patients in a relatively short period of time and because of the danger of damage to the hemopoietic system.

**Regime of Therapy**

Penicillin in doses of 20,000 U every 3–4 hours is given for a period of 3–5 days. Urine cultures are repeated and then a course of streptomycin is given in the following manner:

1. Obtain urine culture for organism.
2. Test the sensitivity of the organism to streptomycin in the patient’s serum. Twenty cc. of blood is sufficient to obtain enough serum.
3. High doses are given: 200,000 U every 5 hours (1 million U daily).
4. Obtain urine cultures after the 1st, 2nd and 3rd days of treatment.
5. Also, on the 3rd day test for blood and urine streptomycin levels taken within 1½ hours after an injection of streptomycin. At this time one determines if the blood and urine levels of streptomycin are high enough to control the organism effectively. This level is determined from the sensitivity of the organism to streptomycin, as in #2 above. An increase in dosage is indicated if the blood and urine levels of streptomycin do not parallel the sensitivity level of the organism.
6. On the 4th and 5th day culture urine.
7. On the 6th day test for blood and urine streptomycin levels.
8. On the 9th day test for blood and urine streptomycin levels.
9. On the 10th day discontinue the streptomycin and take a urine culture.
10. If the patient is afebrile and symptoms have subsided, repeat urine culture 1 week later to ascertain whether or not the urine is sterile.
Our experience has shown that during the course of streptomycin therapy, repeated urine cultures show the reappearance of gram-positive organisms not sensitive to streptomycin. It was also evident that as long as the catheter was in place absolute sterility of the urine for long periods of time was not possible.

In vitro it has been observed that the addition of \( \frac{3}{4} \) cc. of chloral hydrate to a blood agar plate on which the organisms were being cultured cause inhibition of growth of \( B. \text{proteus} \) organisms which were resistant to streptomycin.\(^5\) This has not been established in vivo. However, it does point to a possible means of eliminating these organisms by adding to the irrigating solution a calculated amount of chloral hydrate.

Kidney stone formation was found to be directly proportional to degree of ambulation of the patient.

<table>
<thead>
<tr>
<th>Kidney stones:</th>
<th>14 patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bladder stones:</td>
<td>29 patients</td>
</tr>
<tr>
<td>Kidney and bladder stones:</td>
<td>3 patients</td>
</tr>
</tbody>
</table>

The 3 patients with both bladder and kidney stones were strictly confined to bed at all times due to their general condition.

Transurethral resections were done in 2 cases. One was successful and one unsuccessful. One alcohol injection of the 3rd sacral root was performed after repeated successful injections with novocaine. The alcohol block was not successful, which may have been due to failure actually to reach the motor nerve root.

2. CARE OF BOWELS

Because of the similarity of nerve supply of the descending colon, rectum, and sphincters to that of the bladder and its sphincters, paralysis of this portion of the gastro-intestinal tract results. Likewise, the principle of re-establishing automaticity is similar. We encountered the same condition that was present in Munro's\(^15\) cases. The internal sphincter is spastic and all control of the external sphincter is lost during the stage of spinal shock. Spinal shock apparently lasted up to 2 months. A high colonic irrigation was given on admission if there were any signs of abdominal distention and a history of not emptying the colon for a period of a week or more. This was a common occurrence. Following the irrigation a rectal tube was inserted. Within a week the stage of spinal shock had usually worn off since the time elapsing between injury and arrival at our installation was usually 6 to 8 weeks.

Enemata every 3rd day, at least, were necessary until the patient had established a "reflex bowel." Mild laxatives of mineral oil, 30–60 cc., every other night were helpful. With careful observation impaction should not occur. If it does occur it is best removed by digital manipulation. When the patient has been established on the ward and is familiar with the routines, he is placed on a bed-pan at regular times in the morning so as to encourage the bowel habit. When he has become ambulatory in wheelchair or crutches,
he is taught to get on a commode unassisted. The setting of a definite time to go to stool in the mornings has aided in gaining a conditioned gastrocolic reflex so that by straining with the abdominal and diaphragmatic muscles a movement can be produced. Patients are also taught with the aid of a suspended enema-can to give themselves small enemata in order to start the movement when necessary.

3. CARE OF DECUBITUS ULCERS

Undoubtedly the best care of decubiti is prevention. However, with the exigencies of transportation, ward personnel, and helplessness of the patient in the early stages following the injury, decubitus ulcers can and do develop.

The decubitus ulcer is the most common complication of a spinal cord injury. Fully 85 per cent of patients received had a history of actual presence of a decubitus ulcer. In the patient with skin intact but devoid of its nerve supply a decubitus ulcer can develop within 4 hours from constant pressure on an area. This is strikingly brought out in the development of decubiti over bony prominences such as the sacrum, trochanters, and iliac crests.

The general treatment of a bed sore, once it has developed, is to provide nursing care of the highest degree. These patients must not only be watched carefully to prevent a pressure sore from forming but intense active means must be taken to prevent its extension and enlargement. The patient must be turned every 2 hours from back to side, to opposite side, to abdomen, to back. Use of the trapeze bar and Balkan frame is helpful. A Stryker frame facilitates care of those patients with sacral decubiti. Extreme care must be taken to keep the skin dry at all times. Following bowel movements the perineum and sacral area must be thoroughly cleaned and dry. The bed and sheets must be kept as free of wrinkles as possible. The patient must be lifted in changing position and never dragged. Use of scultetus binders to hold dressings is preferable to adhesive tape. Hot water bottles should never be allowed to come in contact with the skin whenever there is a loss of cutaneous sensation.

The mattress should be of good quality, inner-spring type. A foam-rubber mattress, if available, distributes the weight evenly and is to be preferred. Use of sponge-rubber cushions or rubber rings when the patient is up in wheelchair is necessary.

The maintenance of good nutrition is of paramount importance in the healing of a decubitus ulcer. Whole blood is the next best adjunct to an adequate high-protein diet. In patients with large granulating decubitus ulcers parenteral amino acids and Amigen were given in order to reach a nitrogen balance. It was noted that this type of patient required more frequent transfusions to maintain the red cell count and hemoglobin at a satisfactory level.

Local treatment of a decubitus ulcer can be divided into two phases: operative and non-operative.
(a) Non-operative

In the non-operative phase, in addition to maintaining a positive nitrogen balance and adequate intake of proteins, we have used penicillin jelly and ordinary table sugar applied directly to the bed sore. The ulcer is debrided of necrotic fascia and tissue whenever necessary. The wound is cleansed and then sprinkled with an even layer of sugar. Then copious amounts of penicillin jelly are applied to the area. Well padded dressings are then placed over the decubitus and are changed whenever necessary. This method has proved expedient in preparing the ulcer for surgical procedures to follow. A smooth, clean, even granulating surface is produced that lends itself well to the turning of skin flaps and surgical closure.

Many vehicles for carrying the penicillin were experimented with. It was found that sterile lubricating jelly, water soluble, was best able to carry the penicillin and to release it for action on the bacterial flora when applied to the decubitus. The addition of table sugar has served two theoretical purposes. The sugar may act to serve as a host for parasitic organisms present, thus sparing the tissues; or it may, by dissolution into body tissue fluids present on the surface of the ulcer, form an acid medium which prevents bacterial growth. No conclusive experiments were conducted to prove this contention, but with this method the larger necrotic decubitus ulcers cleared up much more quickly (and in some cases even healed spontaneously) than with dressings of vaselinized gauze, sulfa powders, and ointments. Penicillin jelly is prepared by dissolving one ampule of penicillin (100,000 U) in 20 cc. of distilled water; 4 cc. of this solution are then added to 4 ounces of sterile lubricating jelly. This will give a water soluble vehicle containing 166 U of penicillin per gram.

(b) Operative

To accomplish early ambulation and the consequent promotion of good state of health, it is necessary that decubitus ulcers be healed as quickly as possible. To allow closure by spontaneous healing requires months of watchful waiting. After the patient has passed through the stages of spinal shock, early surgical closure of a decubitus ulcer, whenever possible, is felt to be the best policy. This is especially true of large sacral ulcers that are a constant source of loss of nitrogen. Trochanteric ulcers have proved more difficult to close, but are likewise a large source of nitrogen loss. It has been the practice to prepare an ulcer for surgical closure by maintaining the patient in positive nitrogen balance and by bringing the ulcer to a condition of healing. That is, there must be no necrotic tissue and the floor of the ulcer must be granulating cleanly and evenly. The margin of the ulcer should present signs of epithelization. No anesthesia is required since the presence of an ulcer almost always means denervation of the tissues. In some cases, however, it has been found necessary to administer an anesthetic if the ulcer approximates the level of sensory loss in the patient.
Closure of the sacral ulcer offers the easiest approach:

If the ulcer is sufficiently narrow in its transverse diameter, it may be closed successfully by raising lateral flaps from the surface of the gluteal fascia and approximating them in the midline. If, however, as is usually the case, the transverse diameter is greater than the longitudinal diameter, a diamond-shaped excision of the ulcer is made and a curvilinear incision is made from each inferior angle downward and laterally into the buttock and from the superior angle upward into each lumbar region. The four sector flaps thus outlined are raised from the surface of the gluteal fasciae, rotated centripetally and thus approximated to cover the defect.²

Silk technique may be used throughout. Accurate hemostasis is essential. Some surgeons have used steel wire, tantalum wire, or chromic catgut with cotton for the skin. The results are directly proportioned to the care used in hemostasis and choice and location of incision.

Postoperative care of a patient with a surgical revision of an ulcer is as important as the surgery. Pressure dressings of mechanics waste, foam rubber, cellulose sponges or fluffed gauze are used. An ace bandage is used to keep the dressing in place. Patients are routinely placed on penicillin for the following 4 or 5 postoperative days. The use of a Stryker frame with the patient kept prone for the first $2\frac{3}{4}$ hours postoperatively is advocated. Thereafter, the periods of turning may be increased, always keeping the patient prone for the greatest length of time; 4 hours prone and 1 hour supine have proved satisfactory. Dressing is changed on the 4th or 5th day and alternate sutures removed unless otherwise indicated. On the 10th day the remaining sutures are removed. Return to regular activity and hospital bed can be accomplished in the following 3 weeks.

In the closure of trochanteric ulcers a more serious problem is presented. Some of the smaller ones will lend themselves well to rotation of flaps from the thigh or abdomen. However, the limitations are greater in this area due to lack of sufficient skin for rotating and due to the protrusion of the trochanter.

The closure of the ischial tuberosity decubitus is the most difficult because of its proximity to the rectum. A modified method of Erstlander has proved successful in only one out of three cases of an ischial tuberosity decubitus ulcer.

4. MAINTENANCE OF NUTRITION

In order to accomplish the various stages of rehabilitation of the paraplegic patient, it is of primary and fundamental importance that maintenance of nutrition be considered. Following the onset of the injury anorexia almost invariably occurs. This may be a result of the spinal shock, depressant drugs, concomitant wounds in other regions of the body and mental depression which aggravates the already existing depletion of body tissues. The initial weight loss in a paraplegic in 1 month is very striking. As much as 35 to 50 per cent weight loss has occurred. Our patients were received approximately within 3 months from the date of injury, an occasional one within 3 weeks,
and a few 3 months after injury. On admission all patients presented an
emaciated appearance. The skin was dry and pale, normal tissue turgor was
absent and, in 86 per cent of the cases, a decubitus ulcer was present.

The immediate treatment was to obtain an adequate fluid balance by
forcing fluids per os or parenterally. A 5 per cent solution of glucose and
Amigen was used for parenteral injection. In most cases 2000 cc. per day
was sufficient to bring the patient into fluid balance. In the meantime, the
patient was impressed with the idiom that "food is medicine" and with the
necessity of eating all food served to him regardless of his lack of appetite.
Blood chemistry and cytology were performed within 24 hours of admission.
Study of these reports revealed the need for transfusions of whole blood or
plasma. Blood studies were made routinely every month. If the hemoglobin
was below 80 per cent or the red cell count below 4,000,000, a transfusion of
whole blood was given. Plasma-protein determination taken at the same
time helped give an indication as to the state of protein metabolism. A total
protein level of 6-8 gm. or serum albumin of 3-4 gm. per cent was set as
normal. Blood chemistries were then repeated weekly until normal red
blood cell counts, hemoglobin, total protein and serum albumin levels were
reached. Thereafter, chemistries were performed monthly unless some other
indication appeared.

Long before clinical signs of malnutrition develop, the patient is already
undergoing a depletion of his body stores. By closely regulating the actual
qualitative and quantitative constituents of the diet early clinical signs of
malnutrition may be avoided. If the patient is not able to get an adequate
diet one must be prescribed. The administration of this diet is the crux of the
problem. In spite of making food attractive, urging the patient and even
"standing guard" while he eats, it is often necessary to resort to other
means of feeding the malnourished patient. However, once the patient is
again in positive nitrogen balance the cycle is often broken and he will con-
sume an adequate diet without close observation.

To break the cycle it is often necessary to employ intravenous adminis-
tration of blood, plasma, concentrated albumin; or amino acids. This, at
best, can be termed only a temporary expedient. Protestations by the
patient and also by his blood vessels permit the use of this method for 2 to
3 weeks at most. Tube feeding, by means of a Levin tube using a liquid diet
high in protein and caloric values, will often break the cycle rather sharply.
At this stage in the patient's care he must be dealt with severely and not
allowed to "beg off" the feedings.

During this stage of anorexia the process of reconditioning of the upper
extremities, physical therapy to the lower extremities and encouragement of
activity should not be curtailed. These measures may be less intense than
those prescribed for a patient eating an adequate diet but should not be al-
together discontinued. With the improvement from administration of a
high caloric and high protein diet the feeling of well-being is fostered and
physical activity will automatically increase proportionately. Continued physical activity will maintain the appetite and will prevent the patient from slipping back into a state of anorexia with its insidious development of negative nitrogen balance and signs of malnutrition.

In addition, the prevention and adequate care of decubitus ulcers will aid greatly in decreasing the nitrogen loss from the granulating wound. Eradication of all other sources of infection in the genito-urinary tract and elsewhere (draining sinuses, etc.) must accompany the intensive work in maintaining nutrition.

What may be called an adequate diet depends greatly on the patient’s condition. It is different for the patient losing large amounts of nitrogen from large decubitus ulcers, bedridden and clinically malnourished, than it is for one who is in a good state of health, ambulatory and with healed decubiti. In the former, one may expect the patient to exhibit edema, ascites, open decubitus ulcers and low albumin content in the blood. His basic diet would consist of the following:

- Total calories: 45 cal./kg. of ideal weight.
- Protein: 4 gm./kg. of ideal weight.
- Carbohydrate: 350 gm.
- Supplemental multivitamin therapy.
- Restriction of salt during the stage of ascites or edema.

In the latter instance, the patient’s condition is that of a normally nourished and active paraplegic participating in the ambulation program. His basic diet would consist of the following:

- Total calories: 35 cal./kg. of ideal weight.
- Protein: 1.75 gm./kg. of ideal weight.
- Carbohydrate: 400 gm.
- Supplemental multivitamin therapy.

The patient whose condition lies in between these two extremes would have a diet interpolated between these two examples.

Anyone having had experience with chronically ill or emaciated individuals will be well acquainted with the difficulties encountered in getting a patient to ingest 280 grams of protein. Therefore, portions of food are weighed accurately and from the portion left uneaten on the tray, one can determine how far short the patient has come from the goal prescribed for him. This deficit is made up by supplementary feedings of a milk formula complemented by eggs, skimmed milk, and powdered milk. This formula can be mixed with varying degrees of flavoring extracts to obtain a palatable mixture. Other formulae of similar composition can be evolved to give the supplementary protein and caloric requirements necessary for the patient’s needs. The large quantity of milk has not proved to be an important factor in the formation of kidney stones.
WILLIAM G. KUHN, JR.

MILK FORMULA

<table>
<thead>
<tr>
<th>Food</th>
<th>Gm. or cc.</th>
<th>C</th>
<th>P</th>
<th>F</th>
<th>Cal</th>
<th>Ca</th>
<th>P</th>
<th>Na</th>
<th>Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dryco†</td>
<td>185</td>
<td>85</td>
<td>59</td>
<td>22</td>
<td>775</td>
<td>1.850</td>
<td>1.498</td>
<td>.740</td>
<td>1.480</td>
</tr>
<tr>
<td>Skimmed milk—1 pint</td>
<td>500</td>
<td>25</td>
<td>17.5</td>
<td>1</td>
<td>180</td>
<td>.610</td>
<td>.480</td>
<td>.255</td>
<td>.550</td>
</tr>
<tr>
<td>Egg whites—6</td>
<td>150</td>
<td>—</td>
<td>18.</td>
<td>—</td>
<td>70</td>
<td>.523</td>
<td>.255</td>
<td>.233</td>
<td></td>
</tr>
<tr>
<td>Sugar—1 tablespoon‡</td>
<td>15</td>
<td>15</td>
<td>—</td>
<td>—</td>
<td>60</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Totals</td>
<td>125</td>
<td>94.5</td>
<td>23</td>
<td>1085</td>
<td>2.483</td>
<td>1.999</td>
<td>1.250</td>
<td>2.263</td>
<td></td>
</tr>
</tbody>
</table>

* Figures represent amounts per quart of formula. Flavoring is added to each formula.
† Powdered skimmed milk may be used instead of Dryco. In such formulae, the fat content will be lower but can be compensated for by the addition of cream.
‡ Amount of sugar is varied to taste for individual patient.

5. MANAGEMENT OF PAIN

The control of pain in a patient suffering with a spinal cord injury may, in some instances, become the most prominent feature of treatment. When the pain is severe enough, it may cause anorexia, restlessness, fear of ambulation and complete mental depression. The patient will often refuse to make any attempts to rehabilitate himself and will become prone to urinary infections, malnutrition, and the development of decubiti.

The decision of whether to relieve the pain with habit-forming narcotics or not then resolves itself into a dilemma. This problem has not been satisfactorily solved for the patient with an incomplete lesion. In the patient with a complete lesion, sectioning of the ventral spinothalamic tracts, or a posterior rhizotomy does not involve much risk of causing further insult to the spinal cord. In the patient with an incomplete lesion, one hesitates to perform any operation of such a destructive nature.

Of the patients being reviewed in this paper, approximately 22.5 per cent complained of painful sensations varying from tingling and burning to severe agonizing, knife-like pains. There was no apparent correlation between complete or incomplete lesions.

Division of the ventral spinothalamic tracts was performed in 10 cases (Table 3). These patients all had anatomically complete lesions and were suffering from severe agonizing pains in the lower extremities which were seriously undermining their state of health. The cordotomy was performed at T-3 and T-4 spinal cord segments in all cases except one.

Discussion of Table 3

Case 1 had renal stones and could perceive pain in the kidney region. Cordotomy was, therefore, done unilaterally on the side opposite to the kidney involved.

Case 3 was relieved of all agonizing pain but a burning sensation persisted in the feet. The original injury was to the cauda equina and conus medullaris, and the patient was to have a lysis of cauda equina. Cordotomy was performed in view of the pain present and that antici-
CARE OF SPINAL CORD INJURIES

The patient was 48 years of age and refused to eat unless his pain was controlled.

Case 4 received no relief of pain. On admission to this hospital he was already addicted to morphine. Pain often was relieved by thiamine chloride if administered promptly every 4 hours. The question of psychic overlay was never proved.

Case 5 had a complete gap in spinal cord of 1-2 cm at T-5 and T-6. Repeated cordotomy gave no relief from pain but spasm diminished in the lower extremities and abdomen.

Case 6. The first cordotomy was unsuccessful. Operation was repeated in the same area with success.

Case 7. Following cordotomy motor level rose to T-8 (previously L-1) with complete relief from pain. Four months after operation motor power began to return to the original level.

<table>
<thead>
<tr>
<th>Motor Level at Time of Injury</th>
<th>Level Cordotomy Performed</th>
<th>Motor Level After Cordotomy in Dermatomes</th>
<th>Sensory Level To Pain After Cordotomy in Dermatomes</th>
<th>Relief Obtained in Approximate Per cent</th>
<th>Months Postop.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. T-12</td>
<td>T3-T4 Unilateral</td>
<td>T-12</td>
<td>T-6</td>
<td>50-60%</td>
<td>10</td>
</tr>
<tr>
<td>2. T-10</td>
<td>T3-T4 Bilateral</td>
<td>T-10</td>
<td>T-6</td>
<td>90-100%</td>
<td>4</td>
</tr>
<tr>
<td>3. L-1</td>
<td>T3-T4 Bilateral</td>
<td>L-1</td>
<td>T-8</td>
<td>50-60%</td>
<td>5</td>
</tr>
<tr>
<td>4. L-1</td>
<td>T3-T4 Bilateral</td>
<td>L-1</td>
<td>L-1</td>
<td>No relief</td>
<td>7</td>
</tr>
<tr>
<td>5. T-6</td>
<td>T3-T4 Bilateral</td>
<td>T-6</td>
<td>T-6</td>
<td>No relief</td>
<td>8</td>
</tr>
<tr>
<td>6. Operation repeated</td>
<td></td>
<td>T-6</td>
<td>T-6</td>
<td>No relief</td>
<td>7 1/2</td>
</tr>
<tr>
<td>2 weeks later,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. L-1</td>
<td>T3-T4 Unilateral</td>
<td>T-12</td>
<td>L-1</td>
<td>No relief</td>
<td>6</td>
</tr>
<tr>
<td>8. L-1</td>
<td>T3-T4 Bilateral</td>
<td>T-8</td>
<td>T-6</td>
<td>90-100%</td>
<td>4</td>
</tr>
<tr>
<td>9. T-9</td>
<td>T8-T7 Bilateral</td>
<td>T-9</td>
<td>T-9</td>
<td>90-100%</td>
<td>5</td>
</tr>
<tr>
<td>10. T-10</td>
<td>T3-T4 Bilateral</td>
<td>T-10</td>
<td>T-8</td>
<td>90-100%</td>
<td>10</td>
</tr>
</tbody>
</table>

Traces of return of function were observed in the quadriceps muscle group. At this writing the patient is still free of pain.

Case 8. Following cordotomy the motor level rose to T-8 (previously L-1) with complete relief of pain. The patient was operated upon before cordotomy for a lysis of the cauda equina and a cottonoid sponge was removed together with a sterile abscess. Such severe pain developed postoperatively that tube feeding became necessary to maintain life and cordotomy was, therefore, considered a means of preserving life.

Case 9. Cordotomy was performed 1 and 2 segments respectively above level of original injury at T-9. Pain was not relieved appreciably beyond the estimated 10 per cent.

In Cases 1, 2, 3, 5, 6, 7, 8, 9 and 10 appetite and the general state of nutrition improved markedly both clinically and by laboratory examination of blood levels for protein, hemoglobin, etc. All patients showed relief of pain at first, but over a period of 3 months pain again returned in those unsuccessful cases, 4, 5 and 9.

The author attempts to draw no conclusion from the above table regarding the efficacy of spinothalamic tractotomies. It is, however, his opinion that a cordotomy should be the last resort in attempting to relieve pain. The patient should be examined often enough preoperatively to determine if any
psychic overlay is present and to help make an evaluation of his threshold for pain. Furthermore, in those cases of extreme pain with injury to the distal end of the spinal cord near the conus or cauda equina, utmost care must be taken in performing the operation so that the patient does not become a paraplegic with a superimposed lesion in the upper dorsal area of the spinal cord.

Posterior rhizotomy was performed in 6 cases, all complete lesions. The posterior roots corresponding to the areas from which the pain emanated were sectioned. Relief from pain was immediate. However, pain recurred in the same area 4 months postoperatively in one case, and 3 months postoperatively in another. The recurrence of pain may have been due to the forming of new scar tissue about the severed roots. At operation it was noted that the sensory roots were adherent to the spinal cord which was often covered with dense arachnoid adhesions. Frequently they were torn or buried in fragments of bone spicules.

The decision to perform a cordotomy in the patient with an incomplete lesion should be postponed until everything else has been tried to relieve the pain. Intravenous alcohol and glucose infusions after the method employed by Moore and Karp19 have helped control the pain. The 5 per cent glucose infusion of 1000 or 2000 cc. has also aided in maintaining fluid balance and in creating a sense of well-being which permitted the patient to eat and rest. The sectioning of the sensory roots would be a less damaging procedure than cordotomy and should prove effective particularly in those cases where pain follows a root distribution. The possibility of formation of new scar tissue cannot be entirely obviated and pain may again become a predominating complaint.

The presence of foreign bodies in the cauda equina or substance of the spinal cord can cause excruciating pain. Their removal with lysis of the cauda equina and the freeing of sensory roots involved has often resulted in complete relief of pain. If this fails to control pain a radical cordotomy is often necessary (Case 8, Table 3).

Paravertebral blocks with novocaine were tried on all patients complaining of pain. Relief of pain in each case was only temporary for a period of 5 to 10 minutes. It was felt that this relief was of psychic origin only.

Bilateral sympathectomy was performed on one patient before admission to this hospital. The patient states that he has been relieved of the severe pain but is still annoyed to a slight degree by radicular-like pain. This "pain" is relieved effectively by placebos. No other sympathectomies were performed upon the group of patients being discussed in this paper.

Munro16 reports good results from simple decompression and leaving the dura open. However, in wounds of such explosive nature as those received in warfare, the question of formation of dense compressive scar tissue which may invade the spinal cord and its membranes has prompted battlefront neurosurgeons to close all dural defects.
In those patients complaining of burning, causalgia-like pain, along with their cramp-like pains, nicotinic acid in 50 mgm. doses ½ hour apart for 3 doses daily was tried. Relief was indefinite and difficult to evaluate. On the whole it was ineffectual in these cases. The abstinence from smoking has helped 2 patients in regard to their complaints of dysesthesias. When smoking was resumed these patients noted an immediate aggravation of their pain and burning in the lower extremities.

In the early stages of recovery from an incomplete traumatic injury to the cauda equina, patients frequently complain of severe pain in the lower extremities. A differential diagnosis between returning sensory and motor function and pain due to scar tissue formation or foreign body is difficult to make. In an incomplete lesion with recovery usually there has been evidence of returning sensory function which precedes the onset of pain and which is continued during the period following the onset of pain. It has been noted that the level at which pain originates descends with the descending sensory level. If recovery continues to the distal end of the extremity, the pain will also appear to "run out" of the extremity. Return of motor function follows in 1 or 2 months and is best demonstrated and most often detected by the physical therapist who is treating the patient daily.

It is of some interest that in many patients with an incomplete lesion undergoing progressive recovery, pain occurred relatively early (3 to 4 months after injury). In some complete lesions pain became a prominent feature later in the hospital course.

In almost all cases it was noted that with increased activity, improved nutritional state and occupation of the mind with educational and recreational activities the complaints of pain decreased. The threshold for tolerance of pain may have been elevated and the patients, except those suffering from the more severe types of pain, may have learned to live with and to accept their burden of pain.

6. CONTROL OF SPASM

The treatment of spasm has resolved itself into the problem of deciding to alleviate spasm with or without surgery. Both methods have been employed on the group of patients under discussion.

Non-Surgical Approach

In the case of those patients with an incomplete lesion or unproved anatomically complete lesion, it was thought best to follow a conservative course. Accordingly, various non-surgical methods of combating spasms were attempted.

(1) Curare. A group of 10 patients with marked flexion spasm and with incomplete or unproved anatomically complete lesions of less than 18 months' duration were selected. These patients were given increasingly large doses of curare from 30 mgm. to 80 mgm. daily. The drug was dis-
continued after 8 successive days' administration by intramuscular injections. In 3 cases curare was beneficial in diminishing spasm. However, in these 3 cases high doses (80 mgm.) were employed and the patients became so physically depressed that there was no desire to participate in daily activities on the ward. These patients could not even be forced to use their wheelchairs. There were no toxic symptoms present at any time. To increase the dose beyond 80 mgm. without constant observation for respiratory paralysis was thought unwise and the drug was therefore discontinued. Discontinuance of the drug resulted in immediate recurrence of spasm in the 3 cases where curare was beneficial in diminishing spasm.

(2) Prostigmine. This drug was tried on 23 patients with only partial relief from spastic contractures. These were cases in which spasm caused interference with ambulation only and not with other daily activities. In the more severe cases spasm was not relieved to any appreciable degree subjectively or objectively. Doses of 1.0 mgm. of a 1:4000 solution were given twice daily. It was noted that after 10 to 14 days most patients began to show evidence of developing a tolerance to the drug. The prostigmine was then given 4 times a day and the patients were then given the drug hypodermically for 2 weeks followed by a rest of 1 week. If the dose was increased after 10 to 14 days instead of allowing 1 week's interval before the next series of injections, the patients complained of frequent bowel movements which were explosive in nature.

(3) Bracing and Ambulation. Much has been said controversially on the question of whether or not ambulation and bracing of patients have helped relieve spasm. It has been the experience with this group of patients that ambulation and bracing have not relieved spasm. There was, however, an apparent relief that was short lived at best.

In ambulatory patients with complete lesions, relief was obtained after a few minutes of walking. It was noted that this relief from spasm came on only after the patient became fatigued in his efforts to walk. If he rested on crutches or in a wheelchair his spasm returned with its previous vigor as soon as he felt equal to the task of walking again. If the patient persisted in his walking until exhausted and was then placed in bed, his spasm returned as rapidly as he recovered from fatigue. There was no change in this sequence of events even after months of ambulation.

In patients with incomplete lesions, spasm was relieved by ambulation only in those who showed concomitant return of sensory and motor function. When these patients persisted in walking after reaching the stage of near-exhaustion, the spasm became worse. Over a period of months, however, they were able to prolong this period until spasm was practically completely relieved. It was felt, therefore, that spasm was not relieved by bracing and ambulation alone, but that it was overcome by a combination of return of sensory and motor function and by strengthening of the extensor group of muscles to such a degree that they antagonized the stronger flexor groups of muscles.
Surgical Approach

Previous efforts to alleviate spasm in spinal cord injuries have met success through various surgical approaches. The most common and most successful method has been that of anterior rhizotomy. This method is admittedly a destructive one and is limited to cases of complete lesions or to those in which it may be considered "life saving" in effect. No effort was made to consider the etiology of spasm. Scarff and Pool, working on this same group of patients, attempted to attack the problem by investigating the mechanism causing spasm. Through this approach it was hoped that "a method for relief of spasm might be devised which would not involve destruction of spinal roots and interruption of segmented reflex arcs."

With this in mind an operative program was set up to investigate the pathological changes at the site of injury to the cord. Patients were selected who showed anatomically complete lesions with no return of function over a period of 1 year and with severe incapacitating spasms. Eight such patients were operated upon. At this writing it is 7 to 8 months postoperative.

In those cases in which anatomical division was proven (5 cases), the stumps of the spinal cord were encased in dense scar tissue for a distance of 1.5 to 2 cm. above and below the site of injury. Gross pathological changes of degeneration were visible one or two segments beyond the encasement of scar tissue. In 1 case there was an area of softening surrounded by thick arachnoid adhesions even though the cord was not divided. Laminectomy repeated at a lower level on this patient revealed the extension of this arachnoiditis to almost the entire length of the spinal cord.

After exposure of the cord at the site of injury, electrical diagnostic studies, similar to those used in stimulating peripheral nerves and cerebral cortex for evidences of function, were performed.

In general, stimulation of nerve roots produced a response equal in amplitude to that of external mechanical stimulation. Stimulation of the spinal cord below the level of the lesion caused a greater massive reflex spasm. Stimulation of the cord above the lesion caused only mild local pain and tingling, thus proving the completeness of the lesion. Scarff and Pool also discovered the significant fact that electrical stimulation of the dorsal columns caused greater reflex activity of abdominal and leg muscles than a like stimulus of the ventrolateral columns.

In all cases the stump of the severed cord or the site of injury was freed of adhesions and the scar tissue was excised. Thus, on closure of the dura there was no binding scar tissue to produce traction on the spinal cord.

In 2 cases sectioning of the dorsal columns in the distal stump was performed at the level at which maximum response was obtained.

For a period of 3 to 6 months after operation, all 8 patients benefited by exploratory laminectomy. The lower extremities could be extended pas-
sively with relative ease as compared with the preoperative state, and wheelchair activity was resumed. However, after this latent period all patients, with the exception of the 2 upon whom sectioning of the dorsal columns was performed, gradually returned to their former state of incapacity. One of the 2 who had the dorsal columns sectioned retained relative flaccidity in his right leg while his left leg returned to its former state of spastic flexion. The other developed mild extensor spasm in place of his flexor spasms. These changes did not in either case interfere with ambulation in braces or with wheelchair activity. In fact it was only after the operation that these 2 patients were able to get about. The general condition of both improved considerably.

In 2 other patients, in whom spasm recurred 4 months after operation, anterior rhizotomies were done to preserve life. Both patients were then immediately relieved of all spasm. Their general condition improved within 1 month after rhizotomy, decubiti of trochanteric areas healed, and they became ambulatory.

7. PHYSICAL THERAPY AND RECONDITIONING

This subject is inserted at this point to give added emphasis to the dictum established with this group of patients that physiotherapy rightly begins from the very day of injury and extends throughout the bed-ridden phase and the ambulatory phase. It is as important to the rehabilitation of the patient as are the care of the bladder, decubiti, and maintenance of nutrition. It is often the physical therapist who actually detects the first sign of returning function in these patients. In the daily application of active (not passive) re-educational exercises for the lower extremities, in the unproved anatomically complete lesions, it is the physical therapist who has the best opportunity to observe minute changes in motor function.

Active re-educational exercise is greatly emphasized because it is felt that in many muscles or muscle groups what at first appears to be paralysis is due to extreme weakness or, as is frequently the case, to the fact that the patient has forgotten how to use these groups since the extremity as a whole does not function. Through repetition and constant training the patient may be taught not only to strengthen any single muscle or muscle group, not permanently paralyzed, but also to learn how to substitute the unaffected muscles. Even in the presence of spasticity a patient can be taught to relax and contract on command. If this can be accomplished we consider the patient to have voluntary contraction of the muscles involved. By constant practice the patient can lengthen the period during which he has voluntary control of the spastic muscles. This re-educational training aids greatly in teaching the patient various gaits on crutches.

During the bed-ridden stage, physiotherapy treatment consists mainly of three phases. First, daily radiant heat of 20 to 30 minutes' duration is applied to the affected extremities. Second, massage is given to those patients with edema, contractures and vascular disturbances. It has not been given in
cases of spasticity unless the spasticity is accompanied by the above-mentioned conditions. The third phase of this treatment during the period of confinement is re-educational exercises which are given daily for 30-minute periods. Complete muscle evaluation tests are done every 1 or 2 months and recorded for future comparison and study.

While the physical therapist is concerned primarily with the affected parts, reconditioning of the unaffected muscles must not be overlooked. Development of shoulder girdle, arm, forearm, wrist and finger muscles is essential to walking with braces and crutches. Daily vigorous workouts in bed with bar bells, chest springs, pulleys and weights, and finger grips not only prepare the patient for future ambulation but also aid immeasurably in keeping his appetite up to a level for adequate maintenance of nutrition. Deaver\(^3\) has done much to promote and establish a regime of exercises designed to develop normal muscle groups necessary for use in ambulation. These groups are the arm flexors and extensors, finger and thumb flexors, dorsiflexors of the wrist, and shoulder girdle muscles.

Physical therapy and reconditioning go hand in hand and must be constantly applied by both patient and instructor until the patient has become ambulatory to such a degree that he may be relied upon to perform his exercises himself.

II. AMBULATORY PHASE

1. BRACES

In the past decade there has been a marked scarcity in available reference literature on the subject of braces and orthopedic appliances for paraplegics. This is due, partially, to two factors. First, until World War II there was no urgent need for such literature. The incidence of spinal cord injuries in civilian life was relatively low as compared to a like period in war time. Secondly, modern metallurgical research has produced metal alloys which are lighter than steel but of equally strong composition. It is the opinion of the writer that a field for active investigation for new developments in braces has been opened up.

In practically all cases the paraplegic does not have a deformity of the skeletal make-up of his lower extremities. His difficulties lie within the realm of the neuro-muscular system. The braces need not be of weight-bearing design. In effect, the prosthesis for a paraplegic must be designed to splint the leg so that the knee becomes immobilized in order that the weight be transmitted through the knee joint in a normal manner. In addition, a stop of some sort is necessary to prevent his foot drop from interfering with ambulation.

The ambulatory paraplegic who must literally manipulate the "dead weight" of his lower extremities by action of his quadratus lumborum, abdominus recti or shoulder girdle muscles finds braces of primary importance. The braces must be as light as possible without loss of strength and durability.
We have followed the precept of using long walking calipers without a pelvic band in those cases in which the quadratus lumbarum muscles are preserved. The pelvic band has not been found to add appreciably to hip stability and, in addition, it prevents the unhampered action of the quad-

![Image](image_url)

**Fig. 1.** Comparison of braces. Brace with pelvic band weighs 15 lb. with shoes attached. Brace on right with shoes attached and with its mate weighs 7 lb. 2 oz. Patient wearing lighter brace without pelvic band is able to ambulate more freely.

ratus lumbarum muscle in ambulation. If hip stability becomes a problem, a sacroabdominal belt is used. Girdles of the two-way stretch type have proved satisfactory. If the function of the quadratus lumbarum has been lost, pelvic bands or thoracic cages are necessary even though they add to the total weight of the appliance.

The walking caliper in use with these patients at present is not considered to be the perfect brace (Fig. 1). Much remains to be accomplished.

The caliper is made of a combination of light-weight tool-steel of high quality and duraluminum with a drop-lock at the knee and a drop-foot spring, or permanent stop, if desired.
The upper part of the caliper including the drop-lock joint is made from the steel knee brace on the prosthesis used for below-knee amputations. The joint, therefore, is a ball-bearing joint of great strength and ease of motion. The lock is a fitted ring which drops down to fix the joint when in extension. The lower part of the caliper, from approximately 4 inches below the knee to the caliper pivots at the heel, is made of duraluminum which is riveted to the steel knee joint (duraluminum cannot be welded). This helps decrease the weight markedly without decreasing the strength of the brace. The brace is held in place by a leather cuff at the thigh and calf of the leg. Both cuffs are reinforced with duraluminum bands posteriorly. If needed, a strap is riveted onto the brace at the ankle to hold the calipers firmly in the shoe.

The weight of this brace without shoe is 2 lb. 9 oz. Each shoe weighs 1 lb. A pair of braces with shoes attached would then weigh 7 lb. 2 oz. Thus a walking caliper of great strength, durability, ease of motion through the ball-bearing joint and of light weight was devised using readily accessible material and employing a minimum amount of labor for construction.

We experimented with braces made entirely of duraluminum. The weight of this type of caliper is 1 lb. 9 oz. without shoes. A pair of these braces would weigh 5 lb. 2 oz. with shoes attached. We found some difficulty at first in making a drop-lock knee joint which would allow for the continuity of the duraluminum but which would still be sufficiently strong to withstand the stress and strain put on the brace by a man weighing over 150 lb. A drop-lock joint with German silver facings was tried without success because in patients weighing over 150 lb. the German silver facing wore away. Brass has been suggested as a facing but has not as yet been tried. A drop-lock joint of duraluminum has been suggested using three pieces of duraluminum riveted together and then planed down to size. No facings would then be necessary but the question of durability has not as yet been proved. A pair of calipers of this type would weigh 5 lb. 2 oz. with shoes.

The drop-foot brace used in lesions of the cauda equina is of light-weight 14-gauge steel wire with a posterior leather cuff strengthened by a duraluminum band at the calf. This brace is fastened to the shoe on a pinion through the heel and is detachable from the shoe. Each brace weighs 9 oz. without the shoe.

The advantages of the walking caliper and drop-foot brace which are detachable from the shoe are mainly economical. This type allows for interchange of shoes with little or no expense. In addition, it is easier for a patient to put on and remove calipers if the shoe and brace can be applied independently of each other.

### 2. Special Devices

1. Fig. 2 illustrates a tendon stretcher for correction of drop foot devised by Lt. Colonel R. N. Hatt, M.C., A.U.S. It is comprised of a plaster of Paris shoe across the sole of which is incorporated a length of rubber tubing similar to that used in suction hoses in the operating room. The ends of the tubing are fastened to an upright by means of hooks. This upright and lower extremity are supported on a Thomas half-ring splint by a stocking sling. Buck's extension of moleskin with a spreader is applied to the leg and is fastened to the distal end of the Thomas splint in order to give counter-traction. If the rubber hosing is attached to the upright with the hooks and tension adjusted to bring the foot into neutral position by moving the upright forward or backward, the Achilles tendon can be lengthened gradually. Usually 10 to 14 days of constant traction will suffice to lengthen the tendon. The supporting apparatus may be removed during the night. The plaster of Paris shoe and the patient's foot are checked daily for proper fitting, edema or for the development of blisters or decubiti. This device has been used on 6 patients with good results.

2. Pool devised an electrical device to initiate automatic walking in paraplegics. This consists of a small induction coil imbedded in the subcutaneous tissues, from which wires lead to electrodes which are attached to the surface of a desired motor nerve. Electrical impulses are transmitted through the nerve by placing a primary induction coil over the external surface of the skin. When the current runs through the external or primary coil, an induced current is set up in the buried or secondary coil, which can be controlled by altering the
voltage through the primary coil or varying the distance of primary coil from the skin surface. This induced current is then transmitted to the nerve fibers by the electrodes attached to the nerve. The buried coil and wires are insulated by coating with plexiglass. The electrodes consist of nichrome steel wire. These were inserted into the femoral nerve of one patient with a complete lesion at T-10 and an amputation through proximal \( \frac{1}{2} \) of humerus. Electrical stimulation caused contraction of the quadriceps femoris muscle which could be modified at will by removing or approaching the site over the imbedded coil with the primary coil. This was the first known application of this principle to a human being. No tissue reaction was noted when the coil was removed 5 months later.* Accordingly, a brace was designed which would facilitate this action and which would permit automatic recoil of the leg. This proved unsuccessful and after repeated attempts at ambulation the patient requested removal of the coil. This work is mentioned briefly to serve as a possible stimulus for further physiological research for these patients.

3. AMBULATION

The gait that a patient will use in walking depends largely on two factors. First, it depends upon the level of his lesion. If the patient has preservation

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* Personal communication.
of the quadratus lumborum muscles, he may be successfully taught the "Step-Through" (4-point gait), or he may learn the "Swing-To" (3-point gait). In the event that his lesion is well above the level of the 10th dorsal spinal segment he will have no choice in the matter since he will have to use the "Swing-To" gait. The second factor in choosing a gait is purely a psychological one. The majority of patients discussed in this paper are all young men between the ages of 18 and 30 years of age. A few are between 30 and 48 years of age. All were started in their rehabilitation within 2 or 3 months after their injury. It has been our experience that those patients who are rehabilitated early after injury show a decided preference for the "Step-Through" gait. They express the desire that they want to walk as nearly normally as possible. On the other hand those whose rehabilitation was begun 2 or 3 years after injury stated that their main objective was to "get about" by any method whatsoever. Because of this psychological factor and also because it is the more difficult gait to master, we chose the "Step-Through" gait whenever possible. Moreover, since these patients were received early after injury and recovery was quite possible in cases of incomplete lesions, it was thought more advantageous to teach the "Step-Through" gait first in the event that recovery did occur. Thus, with the progressive recovery of sensory and motor function the patient would not be obliged to learn a new gait which would be more suited to his returning muscle power.

The "Swing-To" gait was taught to all patients as a secondary method of walking. For those with higher lesions it was the gait of choice. In cases of lower dorsal and lumbar lesions it offered another change of pace which would be valuable. It is a faster gait but attracts more sympathetic attention to the patient's plight.

The "Swing-Through" gait (that is, swinging through and beyond the crutches) was not taught to any patient since we found that once the legs passed the perpendicular, all sense of balance was lost, the feet deviated outward and struck the crutch, and the original momentum was the only thing that kept the patient from falling. This pace is an extremely fast one and, in using it, one may out-distance a normal individual. However, the risk of falling is too great.

When the patient's braces have been fitted, he is placed in a standard walker with crutch supports to acclimate himself to the vertical position and to learn the principles of balance. He is shown how small a deviation of the neck and shoulders is sufficient to change the balance. He is then brought to a walking ramp. Mirrors are used to check posture and to reflect his motion as he walks. The ramp is approximately 36 inches wide and the railing is 37 inches high. It should be wide enough so that the patient must make use of his latissimus dorsi muscles in walking and not get into the habit of depending entirely upon the arm and forearm muscles.

The patient starts the four-point or "Step-Through" gait on the ramp by moving his right hand forward. He then tightens his left quadratus lum-
bormuscle which elevates the hip and allows the left leg to swing freely. If the patient still has use of his hip flexors he makes use of these to swing the left leg forward. If the hip flexors are paralyzed he causes the leg to swing forward by a slight rotation of the trunk. This manoeuvre is repeated with the left hand and right leg. Proper use of the quadratus lumborum muscles is essential for a smooth-appearing gait. The patient must be watched care-

![Image](image-url)

**Fig. 8.** (A) Alternate method of getting from wheelchair to bed. Patient lifts himself, using trapeze bar and arm of chair, to sit on edge of bed. He then shifts arm from chair to mattress and pulls himself back onto bed. Legs follow. This method is used when there is limitation in flexion of hips. It is likely to bruise the sacrum, trochanters and legs. (B) Getting into bed from wheelchair. Legs are placed in bed first. Grasping trapeze bar and arm of chair, patient raises himself and swings into bed. This is the method of choice since patient is less likely to bruise sacrum, trochanters or legs.

fully to prevent substituting the shoulder muscles for the quadratus lumborum if the latter is present. This habit, if formed early, is difficult to break as the patient becomes eager for progress and will strive to “break his daily record” by substituting.

The patient is taught to turn around on the ramp, and walk backwards and sidewards so that when he is ready for crutch-walking he has mastered coordination of hands and legs, the principles of balance and the ability to move his legs in any direction in the horizontal plane. In the absence of hip flexors and good quadratus lumborum muscles all the above can be taught by using the shoulder girdle, pectoral and upper extremity muscles as substitutes.

Crutch-walking is essentially the same as walking on the ramp. However,
the patient must learn to balance himself in this more mobile state. The patient has been given crutch exercises long before he is allowed to use them. These exercises consist of learning to move crutches in the proper arc from rear to front rather than with a sidesweep, learning how to catch himself by throwing his crutches ahead and behind his weight, how to balance with one crutch and the proper way to hold and use crutches.

The “Swing-To” gait is taught in the same manner on the ramp and then the patient is given crutches. In addition, exercises on parallel bars are given to strengthen the arms for swinging the body. When on crutches the patient is closely followed by an attendant until he has gained confidence. The “Swing-To” gait consists of virtually raising oneself by bearing down on
hands with the forearm muscles to clear the feet from the floor and then by continued bearing down, dragging the body up to the crutches. The crutches are then placed ahead of the patient and the manoeuvre repeated. Deaver advocates the "Swing-Through" gait as being the gait of choice, but we have found it unsafe on highly polished floors and, therefore, have not used it with this group of patients.

When the patient has become proficient with his crutches he is given an achievement test against time. While he has been preparing himself for ambulation he has also been taught while in the wheelchair stage to dress and undress, to get in and out of bed into wheelchairs (Fig. 3), to enter and leave a tub from a wheelchair, to get on and off a commode from a wheelchair, to get in and out of common chairs, and in and out of a car from a wheelchair (Fig. 4). He is also taught other common every-day activities. When he has reached the stage of crutch-walking he is taught how to do these same things from crutches in addition to walking up and down stairs (Fig. 5), curbs, walking forward, backward and sideways, opening and passing through doors, closing them behind him, getting up off floor, changing gaits and applying his appliances. His time of performing these various acts is recorded and is then checked regularly for improvement.
After he has shown improvement, the patient is interviewed with the idea of obtaining his educational, social, and vocational background. With these records and his medical history, the patient is approached as to his desires for a future occupation. This subject is taken up collectively with the patient and the various departments (Occupational Therapy, Physical Therapy, Reconditioning, Clinical Psychologist, etc.) that have worked with him. Vocations and positions are obtained after consultation with the patient and an explanation of his handicaps and the probable extent of recovery are made known to him. Thus, with the patient ambulatory and with a goal to strive for he is very often spurred on to add to his independence and self respect.

**SUMMARY AND CONCLUSION**

1. A preliminary report on the care and rehabilitation of 118 patients with traumatic transverse myelitis has been presented. Historical data were cited to show that this type of injury was not unknown to practitioners of medicine even in the days of Hippocrates.

2. A system of care that has proved effective in this group of patients was reviewed. The discussion of this system was divided into two phases: the bed-ridden phase and the ambulatory phase. Various procedures applicable to the paraplegic patient were described. Some of these procedures were successful and others were unsuccessful. Many principles of treatment mentioned were not original, but their application to the patient suffering with transverse myelitis was felt to be a new and progressive step towards the goal of an independent and self-supporting existence for these patients.

3. A few tables of statistics and results of treatment were compiled in an effort to point out that the treatment and outlook for these patients is not

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**TABLE 4**

<table>
<thead>
<tr>
<th>Vertebral Level of Injury</th>
<th>Anatomically Complete Lesions*</th>
<th>Incomplete Lesions†</th>
<th>Total No. Patients Ambulatory</th>
<th>Total No. Patients in Series</th>
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</thead>
<tbody>
<tr>
<td>Cervical (C-3 to C-7)</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>10</td>
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<tr>
<td>Thoracic (T-1 to T-6)</td>
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<td>4</td>
<td>21</td>
<td>26</td>
</tr>
<tr>
<td>Thoracic (T-7 to L-1)</td>
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<td>18</td>
<td>40</td>
<td>46</td>
</tr>
<tr>
<td>Cauda equina (L-2 to S-4)</td>
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<td>22</td>
<td>31</td>
<td>32</td>
</tr>
<tr>
<td>Totals</td>
<td>48</td>
<td>49</td>
<td>97</td>
<td>113</td>
</tr>
<tr>
<td>Percentages</td>
<td>77.4%</td>
<td>96%</td>
<td>84%‡</td>
<td></td>
</tr>
</tbody>
</table>

* This group includes those cases in which the cord was seen to be completely transected at operation. There were 62 cases in the entire series.
† This group includes all cases of incompletely transected cords, contusions, and normal-appearing cords with apparent physiological interruption. There were 51 cases in the entire series.
‡ Percentage of total number of patients ambulatory.
hopeless. It has been found that, if given sufficient opportunity, the paraplegic patient will respond with gratifying results.

4. It is the writer's hope that in the realization of the possibilities attainable in the treatment of these patients, past pessimism will be eradicated.

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