Rehabilitation of the neurologically disabled patient: principles, practice, and scientific basis

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Rehabilitation is a therapeutic program specifically directed toward restoring the optimum level of function available to patients with severe permanent disabilities. It complements standard care, which focuses on curing the primary pathology. Preventive rehabilitation is designed to minimize the complications of inactivity that tend to develop during a protracted curative process (contractures, pressure sores, muscle atrophy, cardiopulmonary deconditioning, cognitive dulling). Comprehensive rehabilitation focuses on the restoration of function. It encompasses physical reconditioning, teaching new ways to accomplish the basic tasks of locomotion, object handling, personal care, relationships with family and society, employment, and recreation. The rehabilitation program is largely designed and provided by a team of allied health professionals, each an expert in one area of function. Reverting to a less dominant role, the physician provides leadership by defining the stress (activity) tolerance of the patient's pathology, coordinates the team, and manages intercurrent problems that arise. Comprehensive rehabilitation is an in-hospital program. Less intense elements can be provided in a skilled nursing facility, out-patient clinic, or the patient's home.

The details of the rehabilitation process vary with the nature of the patient's primary pathology. These have been illustrated in this review of the programs for two very diverse situations. Spinal cord injury introduces varying levels of physical incapacitation. Conversely, brain injury primarily creates a cognitive and behavioral deficit. Both are complex problems requiring comprehensive rehabilitation if the impairment is severe.

KEY WORDS • rehabilitation • spinal cord injury • brain injury • head injury
programs, however, must be progressive, as all rehabilitation involves some degree of patient mobilization. Program intensity is determined by the patient’s physiological and lesion stability (Table 1).

### Rehabilitation Programs

#### Preventive Rehabilitation

A bed is the starting point for most patients. Being both convenient and comfortable, there are few, if any, stimuli to move unless active measures are taken. To prevent the complications of prolonged inactivity the following three programs have been developed: skin protection, contracture prevention, and patient activation.

**Skin Protection.** Everyone is aware of the threat of pressure sores, yet prophylactic measures tend to be deferred, as they are inconvenient and patient susceptibility appears quite variable. Also, skin breakdown is commonly attributed to tissue changes from paralysis, infection, moisture, or malnutrition. Research has contradicted these assumptions: these factors may aggravate but do not begin skin ulceration. Excessive pressure is the initiating factor. 45

Lying supine offers the largest area of support. If body weight were equally distributed, skin pressure would be well below the deleterious threshold. Such is not the case. Weight concentration and bone configuration make the sacral area a highly vulnerable site. Skin viability depends on capillary patency (30 mm Hg), yet the average sacral pressure is 60 mm Hg. Initially, obese and well muscled patients are moderately well protected. Time, however, allows the fat to migrate from areas of compression, and inactive muscles atrophy. Thin persons have immediate susceptibility but even they will have an early ulcer-free period. Skin necrosis follows local cell death. As a result there is a 5- to 7-day delay after the initiating period of ischemia. 45

Both the duration and the intensity of the pressure influence skin tolerance. The resulting threshold is an inverse ratio of these two factors. Experimentally, a 2-hour interval of 60-mm Hg pressure caused temporary blood cell stagnation and decreased vascular patency, followed by full recirculation on release. 45

Four hours of pressure resulted in only partial circulatory recovery and edema accumulation. These changes are consistent with those contributing to accumulative effect and eventual ulceration found in a study of high repetition by minor forces. An 8-hour test of continuous pressure showed greater vascular obstruction and skin ulceration 5 to 7 days later. These data provide a firm basis for the clinical rule that skin protection is dependent on changing the patient’s position in bed each 2 hours.

**Contracture Prevention.** As the patient lies in bed, the feet drop into plantar flexion and the knees and hips flex. Failure to counteract these postures by daily moving these joints through their range of motion will allow the positions to become permanent. A seemingly minor 15° deformity at the ankle and knees makes it impossible for the patient to stand upright without manual assistance. Passive mobility is lost because of fibrous tissue stiffening within the muscles. Each muscle fiber and bundle of fibers has a sheath which must lengthen as the joint is moved. Connective tissue is composed of collagen fibers lying in a highly flexible ground substance. Length changes depend on the nonelastic collagen fibers realigning themselves, similarly to the strands of a Chinese finger trap.

The supporting ground substance has a half-life of 7 days and readily loses its flexibility when made immobile. Experimental studies have shown measurable loss of water and chemical components within 2 weeks. By 9 weeks, tissue stiffness is marked. Spasticity accentuates the problem by creating an active restraint to stretch. Paralysis similarly contributes by inducing profound immobility. The volume of connective tissue in the muscle is sufficient to induce permanent contractures in a short time. As there are no visible signs of tissue change, preventive mobilization of each joint must be started early and be done on a daily basis. The upper extremities are just as

<table>
<thead>
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<th>Curative Program</th>
<th>Rehabilitation</th>
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<tr>
<td>emergency state</td>
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<tr>
<td>critical care</td>
<td>preventive: skin protection</td>
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<tr>
<td>subcritical stage</td>
<td>preventive: add joint mobilization</td>
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<tr>
<td>medically/surgically stable</td>
<td>preventive: add patient activation</td>
</tr>
<tr>
<td>protected healing</td>
<td>comprehensive: early strengthening &amp; mobilization; functional training within limits of protection</td>
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<tr>
<td>healed</td>
<td>comprehensive: vigorous program toward maximum capability</td>
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**TABLE 1**

Timetable for blending rehabilitation procedures with the curative program

**TABLE 2**

Specialization of the rehabilitation team

<table>
<thead>
<tr>
<th>Function</th>
<th>Allied Health Professional</th>
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<tbody>
<tr>
<td>joint mobility and muscle strength</td>
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<td>physical therapists</td>
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<td>occupational therapists</td>
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<td>occupational therapists</td>
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<td>bowel &amp; bladder control</td>
<td>nurses</td>
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<tr>
<td>skin protection</td>
<td>nurses</td>
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<tr>
<td>cognition</td>
<td>speech pathologists</td>
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<tr>
<td>communication (language)</td>
<td>speech pathologists</td>
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<td>orthotists</td>
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<td>rehabilitation engineers</td>
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</table>
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Susceptible as the lower limbs, and even greater ranges are used in the activities of daily living.

Patient Activation. The severity of many neurological lesions causes mental dulling and a loss of initiative. Also, it becomes harder to move each day as muscles lose strength quickly, averaging 1% to 5% per day. This is accompanied by cardiopulmonary deconditioning so the energy available for moving also dwindles.

Deliberate stimulation by nursing, with strong physician support, is required to reverse this pattern of deterioration. As early as possible the patients should be encouraged to assist in their self-care and turning in bed, and to sit up in a chair. Brevity of the initial efforts makes these actions seem trivial; instead, they are the start of a very important program of muscle strengthening, cardiopulmonary reconditioning, fibrous tissue mobilization, and skin pressure relief. The challenge to the surgeon is to plan the patient’s care so mobilization is both safe and possible.

Comprehensive Rehabilitation

The demands of daily living involve 10 basic tasks: locomotion, object handling, self-care, bowel and bladder continence, cognition, communication, social adjustment, psychological stability, recreation, and employment. Each must be accomplished in a manner that leaves adequate energy for the others, yet any or all may be disrupted by a neurological lesion.

Objectives and Program Planning. Recovering the patient’s optimum effectiveness in each of these 10 areas is the objective of comprehensive rehabilitation. Design of the appropriate program begins with a functional evaluation to identify the deficits. These findings are correlated with the expectations of spontaneous recovery and therapeutic effectiveness. Realistic goals and an appropriate timetable are defined, with the patient and family involved. They must understand what can be accomplished and what is expected of them. Also, they must be willing to participate.

Recovery of full independence in each functional area is the ideal goal. When severe physical impairment prevents this, the second objective is to develop a system of physical assistance which allows the patient to return home without overtaxing the family or live-in attendant help. Discharge home is the expected result of a successful rehabilitation program. If neither of the above living plans is a predictable outcome, the patient is not a rehabilitation program candidate.

The Multidisciplinary Team. Designing and executing an effective rehabilitation program requires more knowledge than any one professional can command. Consequently, it is managed by a multidisciplinary team composed of physician, nurse, and appropriate allied health professionals. The latter may include a physical therapist, occupational therapist, speech pathologist, medical social worker, psychologist, orthotist, prosthetist, recreational therapist, vocational counselor, and rehabilitation engineer. These are all specialists in one facet of the rehabilitation process (Table 2). Their educational backgrounds include the techniques and concepts of evaluation and program-planning, as well as therapeutic application.

Team patient care alters the practice of the physician. Leadership responsibility remains but it is directed toward supporting, stimulating, and coordinating team input. It is important that the level of healing (fragility) of the patient’s pathology be defined, so that the various allied health professionals can plan appropriately. A second essential is regular and open communication, so progress and problems are readily identified. Mutual respect for the knowledge held by the different professionals is the vital ingredient of effective patient care by a multidisciplinary team.

The Rehabilitation Program. Restoration of the patient’s optimum functional level follows three paths. These are physical development, functional training, and utilization of specialized equipment.

The physical treatment program must begin with measures to heal any pressure sores or correct the obstructive contractures that are present. Then one can proceed with muscle strengthening to prepare the patient for the functions that appear attainable. Functional training is directed toward developing effective substitutions for activities that cannot be resumed spontaneously. Assistive devices may be needed to extend the patient’s functional level or improve efficiency.

Rehabilitation Site. Pressure to reduce costs, unfamiliarity with the requirements for effective rehabilitation, and the lack of clear disability definitions have led to misunderstanding about the therapeutic potential of different rehabilitation facilities.

In-patient status in a comprehensive rehabilitation center is indicated when the patient needs a daily closely coordinated multidisciplinary program, frequent physician involvement, and complex procedures not otherwise available. Other indications are multiple procedures by a single discipline for a patient lacking the endurance for daily travel, and need for a structured environment for the patient to make a major change in life-style.

Out-patient care is appropriate when the patient is capable of traveling by car, and also if the person’s performance level is sufficient that only intermittent stimulation is needed. The most realistic schedule is one in which the patient attends the out-patient facility three times a week. Home-care, unless organized as a special demonstration program, tends to be less frequently indicated. In addition, no special equipment or complex procedures are available to patients at home.
Patients are taught to be responsible for their own skin by regular self inspection.

Skilled nursing facilities are staffed to provide basic feeding, dressing, toileting, and bathing, in addition to dispensing medications. Limited staff time is available to provide stand-by protection when the patients practice walking. Supplementary rehabilitation by professional therapists is performed without interdisciplinary coordination. Again, there is neither the space nor the equipment available for complex or extensive programs.

Summary

The broad principles of rehabilitation apply to all types of protracted or permanent disability but program specifics vary with the patient’s pathology. To demonstrate how different the program can be, two clinical examples have been selected. Spinal cord injury presents the problems of massive paralysis, and brain trauma has cognition as the primary deficit.

Spinal Cord Injury

Multisystem paralysis superimposed on vertebral instability necessitates immediate integration of preventive rehabilitation into the acute-care program. Then, as spine fragility is reduced and physiological stability is regained, the patients are ready to challenge their remaining capability by initiating the early stages of comprehensive rehabilitation.

This continuum also works in reverse as the permanency of most patients' paralysis necessitates a lifelong practice of preventive procedures. Consequently, their rehabilitation program places equal emphasis on the preservation and development of function.

Functional Preservation

Skin Care. The threat of a pressure sore begins with the injury and persists throughout each patient's life. Initial responsibility for skin protection lies with the surgeon. A method of spine immobilization must be selected which allows the nurses to give adequate skin care. Complete pressure relief for the supporting bone prominences every 2 hours is the basic rule. Today, several techniques are available. The most common method is a mixture of “log-rolling” by a nursing team and bridging of local areas with strategically placed pillows. Specialized mattresses (segmented foam, water, mud, fluidized sand) and mechanical beds may reduce nursing demands but none are universally applicable. Thus, some turning must be anticipated. This point is emphasized because the incidence of pressure sores is still 38%.

The signs of skin damage fall into four classes, based on healing potential. Stage I: A persistent reddened area (epidermal damage). Complete pressure relief leads to full healing, but hospitalization is extended about 18 days. Stage II: Cyanosis or blistering (dermal involvement). This too can be restored to normal, but healing will be slower. Stage III: Necrosis or ulceration (full-thickness skin loss including subcutaneous tissues). The lesion will heal but the result will be an area of scar tissue. As normal tissue flexibility has been lost, this area will always be hypersensitive to pressure and shear. Unless the lesion is small, surgical closure is indicated. Healing, however, requires a continuing full skin-protection program. Stage IV: Penetration of the deep fascia with exposure of bone. Healing may be difficult, even with plastic surgery. Hospitalization is extended an average of 133 days.

As the patients become more mobile they are made responsible for the health of their skin. Regular inspection with a mirror and awareness of accumulative micro trauma are taught (Fig. 1). Once patients begin to sit up, protection of the skin under the ischial tuberosities is threatened by pressure and heat. There is insufficient sitting area for adequate pressure distribution. Consequently, RAISE becomes the motto (Routine Alleviation of Ischial Skin Embarrassment). Paraplegic patients are taught to push up for a 15-second skin relief every 15 minutes. Quadriplegic persons learn to RAISE 1 minute each hour using either a forward or side lean. For more extensive paralysis, the family or attendant is taught to provide regular skin relief. Passive protection is also provided by selected cushioning. Four-inch thick, fire-resistant, high-density foam is recommended. Further protection is gained by cutting out the ischial area from the cushion.

Chest Mobilization. Cervical and high thoracic lesions paralyze the intercostal and abdominal muscles. Automatic chest expansion and coughing have been lost. As diaphragm activity pulls the ribs in, contractions with permanent loss of breathing capacity will develop unless an early program of chest stretching (mechanical or manual) is initiated. Patients who
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Fig. 2. RAISE techniques. Upper Left: Push-ups performed by paraplegic and C-6 quadriplegic patients with full elbow extension and effective grasp. Lower Left: Forward lean by a quadriplegic patient who lacks arm strength to raise his body weight. Right: Assisted pressure relief for the dependent person.

Bladder Protection. Continuous drainage by an indwelling (Foley) catheter used to be acceptable. It is convenient and avoids the adverse sequelae of overdistension of the bladder. Urinary tract infections were inevitable and such complications as hydrenephrosis, stones, fistulae, and diverticulae were common. All these problems have been markedly reduced by the introduction of intermittent catheterization with a small-bore (8 mm) catheter. Effectiveness is dependent on systematic timing and sterile technique. As the bladder responds, the frequency of catheterization is reduced. Generally the program objective of a small residual volume is reached by 8 weeks. Most men become catheter-free, and infections are infrequent. Unreliability still requires an external collection system, however.

Contracture Reduction. Early initiation of prophylactic range of motion is very important, as spasticity is common. Each situation aggravates the other. Contractures of recent origin can be corrected by static stretch. For some, serial plaster casts are indicated. These techniques are far easier in patients with complete lesions. The patients with incomplete cervical or thoracic lesions have residual sensation. Discomfort and seemingly greater sensitivity to quick stretch are deterrents to success.

During the spontaneous recovery phase, phenol blockade of muscle function temporarily inhibits spasticity. Percutaneous injections of the muscle’s motor point last 1 to 3 months. Effectiveness can be extended up to 6 months with intraneural infiltration of the motor nerve by surgical exposure. Operative lengthening or release of the contracted spastic muscle...
Functional Potential

The patients' functional potential parallels their neurological level of injury.\textsuperscript{51,128} As this may not correspond to the vertebral lesion, careful identification of existing motor control and sensation is necessary. Completeness of the injury is the second determinant. Modern emergency care and more aggressive early spine management have led to significantly more incomplete lesions. While initial findings do not define the rate or extent of recovery, knowing the potential exists is important for planning a responsive program. Evidence of sacral sparing is sought. The minimal sign is pin-prick sensation on one-half of the anus. Often this is accompanied by some toe movement.

Patient Classification. Both quadriplegia and paraplegia require subclassification to define the patient's potential for independent locomotion. Functional levels are based on the presence of effective strength (Grade 3 is the minimum) in critical muscles and corresponding proprioception.\textsuperscript{125} Manual muscle testing is convenient and useful if appropriately interpreted. Grade 4 (good) is not 4/5 of normal strength. Instead it represents 40% of normal by quantitated measurements.\textsuperscript{4} This has been confirmed anatomically by a comparison of muscle grades and post-mortem motor cell counts.\textsuperscript{122} Grade 3 (fair) strength is equivalent to 15% of normal. Consequently, both values represent considerable weakness, with limited endurance being the major problem.

Proprioception is the critical sensation for function. Only three grades are identifiable: normal, impaired, and absent. Hesitation in giving the correct answer signifies impaired proprioception. Equivalent delays during walking or handling an object can result in functional errors. Patients accommodate by limiting their activities or avoiding the task completely.

Physical Restoration. Strengthening of the muscles available for function is emphasized. Paraplegic patients require upper extremity "power building" to prepare this smaller muscle mass for the arduous task of substituting for paralyzed legs. Quadriplegia and incomplete paralysis present the added need for overcoming disuse weakness in the muscles resulting from initial paralysis. Recovery of one functional level through "root escape" occurs in about one-third of the patients with otherwise complete quadriplegia (RL Waters, unpublished data, 1982).

Effectiveness of recovered muscle strength depends on having unimpeded mobility for the arcs of joint motion used in the various tasks. Consequently, procedures to correct contractures and reduce spasticity are also in progress at this time.

Heterotopic ossification of the extra-articular tissues may lead to late loss of joint mobility.\textsuperscript{147} Generally, the onset is within the first 4 months after injury.\textsuperscript{65} with the incidence varying between 4% and 48%.\textsuperscript{100,140} Significant function limitation occurs in about one-third of the patients. Involvement of the hips is most common (47% to 86%).\textsuperscript{140,153} but it can occur at any joint. Early signs of redness and edema may be misinterpreted as phlebitis, and rest may be inappropriately prescribed.\textsuperscript{65} An elevated serum alkaline phosphatase level and positive bone scan precede visible x-ray changes.\textsuperscript{142} The most effective treatment is early diagnosis and vigorous range of motion several times a day to break up the newly forming bone spicules. A pseudoarthrosis rather than bone overgrowth is the result. If there is less than 50° of hip flexion available (a bare minimum for sitting), wedge resection overlying the joint and early mobilization after the reactive bone is fully mature (an 18-month period) is recommended.\textsuperscript{152} Postoperative bone formation now can be controlled medically with disodium etidronate.\textsuperscript{141}

Functional Development

The objective of rehabilitation is to reestablish independent function at a tolerable energy cost.

Locomotion. Using the following criteria, patients are guided toward either walking or wheelchair travel. Wheelchair candidates with a strong drive to walk are given a clinical trial.\textsuperscript{30} Inability to meet the standing balance and stepping requirements, coupled with increasing efficiency in wheelchair use, generally lead to a spontaneous choice for the latter.

a. Walking. The minimum requirements for the ability to stand are sensation at the hips, trunk control, and joint mobility sufficient for upright balance in knee-ankle-foot locking orthoses (KAFO).\textsuperscript{41,108} With full extension, the hips are locked by slight trunk lordosis. Ankle dorsiflexion of 5° to 10° centers body weight over the mid-foot area.

Taking a step is a greater problem. The foot must be lifted sufficiently to clear the floor for limb advancement.\textsuperscript{113} Paraplegic or incompletely quadriplegic patients have only two options: 1) direct hip and knee flexion or 2) lifting and swinging forward the entire body. The latter is impractical for most patients because arm mass is only one-third that of the lower limbs. Consequently, the determinants of a patient's ability to walk are quadriiceps strength, knee proprioception, freedom from hip flexion contractures, and arm control. There are three neurological patterns.

Patients with S1–L5 lesions have weak ankle plantar flexors and hip abductor/extensor muscles. Crutches are required to compensate for inadequate hip control and dorsiflexion stop/ankle foot orthoses (DFS/AFO) are needed at the ankle\textsuperscript{108,143} (Fig. 3). This gait presents an energy cost per meter traveled that is four times normal.\textsuperscript{88} Young patients find this acceptable; others require a wheelchair for community ambulation.

In patients with L3–4 lesions, quadriiceps weakness
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Fig. 3. Patients with incomplete quadriplegia using crutches for weak hip abductors and extensors. Ankle locking orthoses are worn bilaterally for weak ankle dorsiflexor and plantar flexor muscles. **Left:** This patient's arms and hands are strong enough to manage the crutches. **Right:** Weak arms and hands necessitate forearm troughs.

(less than Grade 4) has been added to the patient's disability. The combined impairment of ankle plantar flexor and quadriceps and hip extensor muscles leaves the patient with a tantalizing level of control but inadequate to walk without KAFO.\(^{27,40}\) If the paralysis is sufficiently asymmetrical to preserve Grade 4 (good) strength on one side, household or limited community ambulation with one AFO and one KAFO is practical\(^{47}\) (Fig. 4). When bilateral KAFO's are required, walking becomes impractical. The ability of these patients to use a reciprocal step is no more efficient than the swing-through technique. Some patients continue to use their orthoses for exercise, however.\(^{126}\) All need a lengthy clinical trial before a wheelchair is accepted as their mode of travel.

With lesions at the T12–L1 level, motor control and sensation at the hips and distally are absent. Now a swing-through gait is needed, yet it raises the energy cost per meter to six times normal.\(^{28}\) Only the rare patient who can attain a reasonable velocity (60 m/min) persists in this endeavor (Fig. 5).

b. Wheelchair Ambulation. All patients with significant lower limb paralysis should be trained as wheelchair travelers. The choice of chair, besides the requirement of fitting the patient, will be dictated by the patient's arm strength.\(^{72}\) Paraplegic patients can be fully independent unless they are obese, very spastic, or have significant scarring from previous pressure sores. Independent control includes managing curbs (Fig. 6). Strong, lithe, quadriplegic patients with C-6 level function also have this capability.\(^{30}\) Endurance is limited by the intercostal paralysis that accompanies high-level paraplegia and quadriplegia.

Electric wheelchairs should be prescribed for all patients with C-5 or higher functional levels. While some patients can manually move the chair short distances, the energy cost is too high for reliable performance. They also need a light-weight chair that families can lift in and out of the car. Remote controls (chin or tongue switch) preserve independent travel for the patient with C-4 and more involvement.

c. Driving. Patients with paraplegia or low quadriplegia (C-6) are capable of driving a regular car if hand controls are substituted for the foot pedals.\(^{121}\) The quadriplegic patients also require a swivel knob on the steering wheel. Specially designed vans, high enough to accept patients sitting in their chair, and fitted with an automatic lift, enable persons with less arm strength and grasp to transfer and drive independently (Fig. 7).
Object Handling. Paraplegia does not impair the patient’s desk-top type activities, but lifting things from the floor or handling heavy structures may present difficulties. For the ambulatory patient, the limitations are orthotic inflexibility and lower extremity weakness. Trunk instability restricts the lifting ability of patients in a wheelchair. This is particularly significant with upper thoracic lesions. Such factors are pertinent to vocational planning.

Quadriplegic impairment of hand and arm function significantly increases with each higher level of paralysis. Both trunk instability and endurance limitations are common to all levels.\textsuperscript{136}

For patients with a T-1 lesion, intrinsic muscle paralysis limits fine hand control (Fig. 8 upper left). This restricts vocational choices. In C-8 level lesions, finger flexor paralysis is the added loss, leaving no active grasp. An initial substitute is a “wrist-driven” orthosis. Surgical transfer of the long wrist extensor to the finger flexor muscles offers a definitive answer.

In defining the C-7 functional level, custom has changed the terminology at this vertebral level, as the
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**Fig. 8.** *Upper Left:* Metacarpal extensor stop orthosis induces mild flexion for better grasp and prevention of a hyperextension contracture in a patient with intrinsic paralysis. *Upper Right:* A patient with C-6 functional quadriplegia uses active wrist extension to flex the fingers; the thumb is stabilized in opposition. *Lower Left:* Patient with a C-5 functional level, with paralyzed wrist extensors. Passive finger flexion provides grasp. This patient still has independent arm function. *Lower Right:* For patients with a C-4 functional level, hand activity is replaced with a mouth-stick. Passive hand orthoses prevent deformity.

Focus has shifted from loss of function to that remaining. Sensation is intact in the thumb, and index and long fingers. Also, the two radial wrist extensor muscles suffer only from disuse. A "wrist-driven flexor hinge" orthosis provides immediate grasp56,91 (Fig. 8 upper right), and also assists in the development of a natural "tenodesis" as the permanent answer. Careful stretching of the joints with encouragement of contracture formation in the long finger extensor and flexor muscles and wrist extensor strengthening offer the optimum result.104 Surgical replacement of similar function is appropriate for those patients who will not be using their hands for manual transfer.96,114,187 The associated triceps weakness makes stabilizing some objects difficult.

For patients with a C-5 functional level, remaining function is partial innervation of the elbow flexors and shoulder abductor/flexor muscles, and perhaps limited sensation in the thumb. Grasp can be replaced with a passive ratchet orthosis56 (Fig. 8 lower left). Functional electrical stimulation with implanted wires is still at the experimental stage.106 Reliance on vision for sensory feedback limits hand use to one side. Initially the arm muscles are very weak, but through "root escape" and intense therapy they generally attain Grade 3+ or 4 strength. Only light objects can be managed.

In patients with a C-4 or higher functional level, all hand and arm control and sensation are lost (Fig. 8 lower right). The small amount of shoulder shrug available is tantalizing but not useful because of trunk instability. Environmental controls activated by head or tongue switches are the sole source of independence of these patients42,56,131 (Fig. 9).

**Self-Care, Writing, and Community Skills.** As higher levels of paraplegia compromise trunk balance, arm use is limited. Consequently, customary procedures...
FIG. 9. This severely paralyzed and blind patient is gainfully employed as a marriage and child counselor through the assistance of remote control equipment. The headset and a collar of micro switches enables her to operate automatic dialing telephones and a tape recorder. Photograph by courtesy of Project Threshold, Rehabilitation Engineering Center, Rancho Los Amigos Hospital.

must be modified and energy conservation techniques taught. Unsupported sitting balance and 100° straight-leg raising should be gained before lower extremity dressing is initiated.

Quadriplegic patients must also accommodate for their limited grasp. Only the C-6 functional level permits full physical independence. A program of approximately 6 months is required for development of skills for these patients. Their special equipment is a button hook and an electric typewriter. With C-5 function, light hygiene, feeding, upper body dressing, and desk skills are logical goals. Several types of adaptive equipment are needed. Higher levels of paralysis make the patient dependent for personal care, but writing, page turning, and operating recorders are practicable with a mouth-stick.

Sexual Adjustment. As the sexual functions are controlled by the S2–4 spinal cord segments, even minor permanent lesions in this region cause some difficulties. The anal reflex (by rectal examination) and pin-prick sensation of the penis, scrotum, and perineal saddle define the patient's physical potential. Upper motor lesions permit the majority of patients to complete coitus, but few with lower motor lesions have this ability. Only the men with quite incomplete lesions can sire children. Few women can have an orgasm, but their menses and child-bearing potential return. To assist patients in handling their limitation, sex counseling is a part of their rehabilitation. Sex partners are included in counseling sessions, since much of the eventual satisfaction depends on learning to cope.

Recruitment. Leisure time is a major problem for the spinal cord-injured patient. Most are greatly in need of both an energy and emotional outlet, yet television viewing and solitude are their post-injury tendencies. Recreational therapy teaches them more effective activities. Wheelchair sports provide and offer the rewards of intense competition, physical conditioning, and evidence that the patient can be effective in a physical world.

Employment. The necessity of crutches or a wheelchair for locomotion disqualifies paraplegic patients from jobs requiring brawn. Hence, brain power and manual dexterity are the marketable skills of these patients. For those with quadriplegia, only the intellectual fields are appropriate. Consequently, both groups commonly need considerable counseling and specialized training, which increases the employment rate of high school graduates from 40% to 61%; the advantage of a college degree raised chances of employment from 54% to 87%. The patients' attitude toward their physical impairment also proved significant. Those who related their paralysis inability to accomplishing certain activities (whether work or recreational) proved to be better vocational candidates than the patients who just focused on the fact they were no longer physically whole.

Brain Injury

Since brain injuries range from a brief concussion to permanent coma, any discussion of rehabilitation must be preceded by a definition of the pathology being considered. Three measurement systems are in use: persistence of posttraumatic amnesia (PTA) is a retrospective determinant, while depth and duration of coma provide concurrent information. More than 24 hours of PTA was related to a severe lesion; persistence for 1 week was a severe injury. In 1942, the corresponding disability intervals were 8 weeks and 8 months. Amnesia for several weeks is not uncommon in today's rehabilitation patients.

The Glasgow Coma Scale of the various arousal signs identifies the upper threshold of coma as inability to open the eyes, obey commands, or utter words. The absence of these signs for 6 hours defined a "severe head injury." In a three-country study of outcome in 700 patients (60% in coma for 3 days, and 91% with 1 week of PTA), the 49% who survived represented the pool of patients for rehabilitation. Recovery was good in 45% (minor neurological or psychological deficit), moderate for 32% (independent...
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in a sheltered environment), and poor for 22% (18% dependent and 4% vegetative).

There is another group of patients who remain in coma for weeks. While all patients need early preventive rehabilitation, further care should be related to the duration of coma. Voluntary motion on command proved to be the most reliable sign that useful consciousness had returned.19,124 This is stricter than the Glasgow Coma Scale threshold.

For adults, the critical delay in willed motion return was 4 weeks.124 Of those responding within this period, 86% recovered good cognition and independent walking. None of those who were in coma for a longer time became ambulatory, and only 17% achieved wheelchair independence. Children had a better rate of recovery,19 with willed motion returning by 6 weeks, and 93% became fully ambulatory. A 3-month delay allowed only 62% of those remaining to reach this functional level. In this second group, the instance of total disability was 15% compared to 2% for those who awoke within 6 weeks. Even with very prolonged comas, only 33% of the children suffered total disability.

Indications for Rehabilitation

The preceding studies indicate that most patients will arouse from coma within a few days. These patients have significant cognitive or physical deficits for which a program of comprehensive rehabilitation is indicated.30,62 Expectant care for comatose adults should cease after 4 weeks unless the family wants the patient home in any condition.124 In these circumstances, the rehabilitation effort is aimed at training the family and providing the necessary equipment.76 However, children are an exception. Since they may respond favorably after lengthy periods of coma, and few are rejected by their families, expectant care for these patients should continue for 6 months.19

Preventive Rehabilitation

The value of rehabilitation following brain injury was documented by Travis144 incidental to her study in monkeys of pyramidal tract dysfunction with bilateral precentral cortical ablation. Finding more disability than was consistent with the neurological signs, she studied a second group of monkeys. After surgery, the animals frequently had a passive range of motion and received assistance in using their emerging function each day. The study resulted in the animals regaining normal function except for absent digit differentiation. Later investigators have confirmed these findings.22,156 While extrapyramidal tract function is more effective in monkeys than humans, the advantages of early mobilization and functional assistance apply to both species.

Skin Protection. Brain-injured patients present two problems. Their inertia necessitates the basic 2-hour turning program. In addition, their agitation may have caused abrasion of the heels. Well padded plaster casts absorb this trauma.111

Contracture Prevention. Deformities may result from both persistent lack of motion and active nonfunctional posturing. Spasticity and primitive flexor (or extensor) reactions prevent adequate stretching of the fibrous tissues80 (Fig. 10). If the involuntary muscle activity is mild, splints will maintain a functional position between the periods of exercise. More intense muscle force requires bivalved or drop-out casts to avoid heel, patellar, or elbow skin breakdown.

Patient Activation. Organized cognitive stimulation for the comatose patient leads to earlier use of recover-
more tolerant: splints or traction will be adequate treatment during the initial 7- to 10-day period required for the brain injury to subside to a state safe for general anesthesia. When cast bracing is not appropriate, open reduction and internal fixation is generally required because agitation and spasticity make traction and static casts ineffective.47

**Comprehensive Rehabilitation**

Brain injury creates both mental and physical disability. While the former is more common, physical rehabilitation was initiated first because there were applicable techniques already available. Traditionally, equivalent mental rehabilitation had to await the formulation of effective cognition assessment techniques. Only then could goal-oriented therapeutic programs be formulated. However, these are recent accomplishments,14,47 the need for which is substantiated by "good" rather than "normal" being the highest rating in outcome scales. Today's rehabilitation centers for the brain-injured provide coordinated programs for both mental and physical dysfunction.

**Mental Rehabilitation**

The therapeutic objective of mental rehabilitation is to minimize the number of adverse factors that need to be managed, and to teach accommodation techniques.

**Cognitive Rehabilitation Program.** Brain injury reduces the patient's ability to select the necessary and relevant events from the continuum of fluctuating internal and external stimuli bombarding them. Instead, they react to each stimulus as a separate entity. The result is confusion, disorganization, inappropriateness, lack of inhibition, and reduced initiative.56

Attention, memory, and judgment are the gross deficits.3 By stepwise training in analysis, discrimination, seriation, categorization, association, memory retrieval strategies, and similar skills, spontaneous recovery is challenged and channeled into useful mental function.11 For the permanent deficits, compensatory mechanisms are taught. The strategy is first to define the patient's current level of function57 (Table 3), then a therapeutic program is designed in which the patient progresses through a hierarchical sequence of increasingly more complex demands and performance57 (Table 4).

The first 6 months following injury is the primary period of cognitive recovery.130 During this interval of brain plasticity, therapeutic intervention is most effective. This is an in-patient program beginning with organized stimulation for the semicomatose patient and continuing until a structured environment with graded stimulation is no longer of benefit. Few families can provide such a therapeutic situation, nor can they tolerate, on a continual basis, the patient's early aberrant actions.13

Cognition is such a dominant factor in language that speech pathologists have become leaders in cog-

### TABLE 3

**Levels of cognitive function**

<table>
<thead>
<tr>
<th>Level of Function</th>
<th>Action</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>no response</td>
<td>reacts to no stimuli</td>
</tr>
<tr>
<td>II</td>
<td>generalized response</td>
<td>inconsistent, non-purposeful</td>
</tr>
<tr>
<td>III</td>
<td>localized response</td>
<td>specific but inconsistent</td>
</tr>
<tr>
<td>IV</td>
<td>confused, agitated</td>
<td>highly active, undiscriminating</td>
</tr>
<tr>
<td>V</td>
<td>confused, inappropriate</td>
<td>alert, distracted by complexity</td>
</tr>
<tr>
<td>VI</td>
<td>confused, appropriate</td>
<td>consistent but needs direction</td>
</tr>
<tr>
<td>VII</td>
<td>automatic, appropriate</td>
<td>self-care independent, home &amp; community skills supervised, prevocational evaluation</td>
</tr>
<tr>
<td>VIII</td>
<td>purposeful, appropriate</td>
<td>home &amp; community skills independent, vocational rehabilitation</td>
</tr>
</tbody>
</table>

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### TABLE 4

**Cognitive management progression**

<table>
<thead>
<tr>
<th>Cognition Levels</th>
<th>Recovery Phase</th>
<th>Therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>II, III</td>
<td>decreased response</td>
<td>stimulation</td>
</tr>
<tr>
<td>IV</td>
<td>agitated response</td>
<td>structure</td>
</tr>
<tr>
<td>V, VI</td>
<td>confused response</td>
<td>structure</td>
</tr>
<tr>
<td>VII, VIII</td>
<td>automatic response</td>
<td>community</td>
</tr>
</tbody>
</table>

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Nursing provides the 24-hour continuity. Environmental stimulation is limited, support is provided, and newly learned skills reinforced by daily use.

Communication. Language impairment following closed-brain injuries relates to cognition. Focal brain lesions lead to specific language losses similar to the sequelae of a cerebral vascular accident. Specific instruction, however, must wait until cognitive clearing allows the patient to exercise self-correction; hence, this tends to be an out-patient program (Table 5).

Behavior. Asocial behavior is not an uncommon sequela to acute brain injury. The patients are less able to handle stress, yet they must cope with physical and cognitive deficits as well as daily demands. The result is exaggeration of the adverse qualities of the patient's pre-morbid personality, leading to greater anxiety, depression, intolerance, and impatience. To lessen these reactions, specific training in emotional accommodation is provided by the psychologists and medical social workers. In addition, the physical and cognitive programs indirectly contribute by reducing the stress.

Behavioral outcome is implied by the patients' early course. While 80% of the active patients showed improvement, in 42% of these restlessness and agitation later implied a need for supervision. Only 24% of the patients who act appropriately had these limitations. Few of the sluggish or immobile patients improved (15%).

Social Adjustment. The families are brought into the therapeutic program very early to have them become familiar with and accepting of the patient's disabled state. A second purpose is to teach family members how to contribute to the patient's progress. Both skills (coping and assisting) will be needed at home. Following discharge, continued guidance and support by the entire rehabilitation team are needed. The patients also need opportunities for socializing with outsiders and families, to gain support by sharing their problems with others who have had a similar burden imposed upon them.

Physical Rehabilitation

Three patterns of paralysis are seen in head-injured patients: hemiplegia, ataxia, and quadriparesis (bilateral hemiplegia). In one series the incidence among 108 survivors was 20%, 6%, and 17%, respectively. Hemiplegic and ataxic patients regained physical independence but those with quadriparesis were less successful.

Locomotion. Hemiplegia generally restricts muscle control to patterns of mass flexion and extension. This allows most patients to become ambulatory, as considerable compensation is available from the normal function remaining in the sound limb (Fig. 11). Brain-injured patients are younger, physically more vigorous, and have a longer recovery period (18 versus 6 months) than stroke victims, and therefore tend to do better. There are three major problems that require correction: 1) an inadequate body image challenges balance; 2) contractures and spasticity restrict mobility; and 3) insufficient muscle action causes problems in effective stepping or stance stability. Early mobilization reflex training and functional electrical stimulation have led to improved outcome. Well fitted orthoses also help to prevent contractures and assist function.

Spasticity or contractures that continue to obstruct the patient's rehabilitation program necessitate physician intervention. Contractures require graded selec-

Fig. 11. Levels of function of hemiplegia: maximum orthotic need is one ankle locking orthosis and a cane.

<table>
<thead>
<tr>
<th>Communication Level</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>normal phrasing</td>
</tr>
<tr>
<td>II</td>
<td>single idea, single word</td>
</tr>
<tr>
<td>III</td>
<td>gestures</td>
</tr>
<tr>
<td>IV</td>
<td>coincidental automatic reaction</td>
</tr>
</tbody>
</table>
Fig. 12. Patient with quadriplegia (asymmetrical bilateral hemiplegia) with inadequate standing balance (left), and ataxic patient (right).

Spasticity can be reduced temporarily with phenol infiltration intramuscularly (for 1 to 3 months) or intraneurally by surgery (for 6 to 9 months).

Following the 18-month period of spontaneous recovery, definitive surgical correction is indicated. Selection of the appropriate tendon transfers, releases, or neurectomies has been made more accurate by dynamic electromyography (EMG) to define exactly how the muscles are functioning.

Ataxia causes inaccurate, not inappropriate, motor control (Fig. 12). Early strengthening, balance coordination training, and functional practice accelerate spontaneous gains. The traumatic ataxic patient continues to improve slowly for several years. This suggests tract contusion from brain-stem trauma rather than cortical damage.

Quadriplegia essentially is bilateral hemiplegia. Lacking a normal side for accommodation, the patient’s functional recovery is severely limited (Fig. 12). Some become wheelchair-independent, but unless the residual deficit is minor the ability to walk is not regained.

Object Handling. The therapists focus their efforts on advancing all neural recovery to a functional level. Hemiparesis limits hand and arm function through the loss of selective control and the restraints created by spasticity and contractures. Combining functional electrical stimulation and biofeedback has proved more effective than the traditional methods in augmenting the use of emerging selective control. The effects of spasticity are reduced by contracture correction. Outcome is proportional to the degree of selective control recovered. Usually residual deficits restrict the hand to the role of an assistant, with primary function being transferred to the other (non-paralytic) extremity, whether or not it previously was the dominant side. Hand function and comfort can be improved by selective surgical release of spastic or contracted muscles. An accurate functional diagnosis is made through dynamic EMG.

Ataxia inhibits hand and arm function through the inaccuracies it imposes. Early strengthening and training in functional accuracy and visual guidance of the hand supplement spontaneous recovery. Patients with persistent perceptual and cognitive limitations have difficulties in driving. This is unrelated to any physical deficits.

Self-Care. In patients with hemiplegia, the sound side is trained to accomplish the necessary tasks in a one-handed manner. Specific training has to await recovery to the “confused but appropriate” level. Ataxic patients are taught how to adapt to their inaccurate control.

Employment. Few patients with intellectually oriented vocations will be able to return to their former situation because of cognitive loss in abstract thinking, flexibility, and creative planning. If physically intact, they can be directed into areas of a lower intellectual level or focused on brawn. Those with combined physical and cognitive deficits have few vocational outlets. Both ataxia and hemiplegia impair hand function. Communication limitations bar jobs requiring personality, such as a receptionist position.

Summary

By combining intense curative and rehabilitative efforts, the sequelae of a catastrophic injury can be minimized. For persons with spinal cord lesions, the physical losses from paralysis are most evident. Of equal significance are the psychosocial problems that must be managed.

Following brain injury, cognitive and behavioral disabilities are the most common sequelae. Yet about 40% of patients also have significant physical impairment. An adequate rehabilitation program, thus, must be capable of providing the necessary mix of physical, cognitive, and psychosocial functional development. Reentry into community living by either group of patients presents a highly complex challenge, because society is not fully prepared to receive the disabled as peers.

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