RECOVERY OF SPINAL CORD FUNCTION

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Key words: Neurological sequelae after spinal cord damage may be simply divided into those seen in: (a) the acute stage of management and (b) the later stage of management.

Such a simple division achieves an emphasis in that late changes do occur, compared to acute changes in the first six to eight weeks. These have not been well reported. In incomplete cord division, late phenomena appear and restoration of function proceeds for variable periods of time, depending on not only the damage but on the motivation and the training that a particular individual will subject himself to. In complete cases, however, from any cause, whether it be injury, vascular or infection, late neurological restoration and its use by patients is less well known, in fact the literature is poor and the effect on general functions not well documented.

In a series of cervical injuries with spinal cord damage reviewed by the present author and reported in 1973 to a symposium in Phoenix 37 per cent of cases admitted complete were in fact incomplete (see Table I). In a group of 48 of these cases useful recovery occurred overall in 41 per cent whilst in the incomplete cases 44 per cent showed useful recovery. Similar results have already been reported by Frankel *et al.* (1969) (see Table II).

Burke and Murray (1976) recently reported on neurological recovery in 115 lumbo-dorsal cases which showed that 11 per cent admitted complete were incomplete. When these figures were analysed, 80 per cent of incomplete cases in the lumbo-dorsal series showed useful recovery (see Table IV). A summary of

Table I
Review of cervical fractures and fracture dislocations
Perth, Western Australia
Neurological state on admission and discharge

	Admission	Discharge
Complete	81 = 35%	51 = 22%
Incomplete	155 = 65%	185 = 78%
Total	236	236

37% cases admitted complete are incomplete

Table II
Neurological sequelae of cervical spinal cord injury

Total cases reviewed	48	
Useful recovery (D and E)		
Frankel (1969)	20	41%
Cases admitted incomplete	36	75%
Useful recovery	16	44%
No recovery	20	56%

the overall figures showed that 41 per cent of all cervical and 36 per cent of all lumbo-dorsal cases displayed a noted improvement, with incomplete cases showing better recovery as expected than Neurological change in the early stages is of use in prognosis. In an extensive clinical review the results shown in Tables I, II, III, IV and V emerged.

Such acute observations as shown in the Tables, lasting only a few months, should make us more observant of late features, of use where a continuance of the life style of over 100,000 people in the United States of America alone is thus affected. This paper therefore deals with a few observations on this subject in the body areas below the initial complete cord transection.

Table III
Review of lumbo-dorsal fractures and fracture dislocations
(Burke & Murray—Melbourne 1976)
Neurological state on admission and discharge

	Admission	Discharge
Complete	74 = 65%	66 = 57%
Incomplete	41 = 35%	49 = 43%
Total	115	115

11% of cases admitted complete are incomplete

Table IV
Neurological sequelae of lumbo-dorsal spinal cord injury
(Burke & Murray—Melbourne 1976)

Total cases	115
Useful recovery	41 = 36%
Cases admitted incomplete	41
Useful recovery	33 = 80%
No recovery	8 = 20%
Cases admitted complete	74
Useful recovery	8 = 11%
No recovery	66 = 89%

Table V
Neurological sequelae of spinal cord injury

Cervical cases (total series)	
Useful recovery	41%
Useful recovery in incomplete cases	48%
Useful recovery in complete cases	18%
Lumbo dorsal cases (total series)	
Useful recovery overall	36%
Useful recovery in incomplete cases	80%
Useful recovery in complete cases	11%

Treatment of the complete and incomplete spinal paralytic has long stressed the features of physical training, particularly in relationship to motor function, and yet such motor function needs sensory input or perception as had been observed by Guttmann (1963) in discussing recent advances made in the care of tetraplegics and paraplegics. One of the earliest observers of such sensory phenomena in complete paraplegia (distinct from motor manifestation) was Henry Head (1920). Head observed that the sensation associated with bladder distention such as hyperhidrosis and flushing were unpleasant and thus were used; whilst the normal pleasurable sensation experienced by bladder evacuation was not appreciated. For a long period of time, observers such as Head (1920), Guttmann (1963), and Munro (1943) have noticed that patients with complete paraplegia and tetraplegia report variable ill-defined sensory phenomena in the areas below their level of transection, e.g. burning, deep localisation, and spasm, which whilst it has a motor component also has a sensory modality.

Early sparing and restoration of neurological features in the first six to eight weeks usually falls into patterns determined by cord damage.

Correlation of post mortem studies have elucidated these patterns at least partly, Wolman (1964), Hughes (1851), Bedbrook and Kakulas (1969), and Schneider (1956) so that the Brown-Sequard phenomenon and the central cord phenomenon have a better prognosis than others. The anterior cord syndrome and posterior cord syndrome have been well documented but do not always carry such a good prognosis. Rapid improvement indicates good prognosis, whilst slow recovery is usually (but not always, particularly in the older age groups) indicative of finally poorer function (Table VI).

There is no doubt from the experimental work summarised recently by Osterholm (1974) that anoxia and hypotension are two factors of great significance in the final pathological state. Minor early deterioration of a few segments on dermatome examination is not usually of grave prognosis, whilst gross deterioration is rare but has been well documented. Frankel (1969).

Table VI
Neurological sequelae of spinal cord injury

Cervical	
37%	of cases admitted as complete are incomplete
Lumbo-dorsal	
11%	of cases admitted as complete are incomplete

Over the past 22 years in a gross series of over 1000 cases a small group of patients have been observed who individually had themselves made observations on the sensory state of their limbs and trunk below the level of their complete cord transections. Such observations were noted in the routine regular follow-up examinations undertaken when each person is checked neurologically. As such observations were recorded their remarks were kept separate and have now been collated, each patient being re-interviewed with details taken once more. Any initially incomplete cases have been excluded, thus only such persons well documented as being complete on initial examination and on discharge from primary care have been included. Finally 17 cases were available for detailed survey. One other patient's records were discarded, although of great interest. This female of 42 years showed a sensory awareness to a very useful level (S₄ on the Medical Research Council Scale); but as her admission was before careful repeated central nervous system examinations were recorded, the author could not be certain of her original admission state.

Two case papers will be briefly quoted to illustrate the type of case examined:

W. L., male, age 45, admitted 1957. Fracture dislocation T₁₂ on L₁ with complete paraplegia both motor and sensory below the segment of L₁. Has remained a complete paraplegic for 19 years. In 1967 operative interference for a claw toe was advised. Subsequent to the bony and ligamentous operative interference he noted:

- (a) Clenching his fingers and breathing deeply gave him the feeling of closing his toes.
- (b) In using a hand saw he felt the rasping of the saw, not in his hands but in his feet.
- (c) A varicose ulcer developed on his leg in 1975, by 1976 he could site the position of the ulcer by touch.
- (d) In 1971 he commenced to get what he called ischial sensation on sitting long periods. Such burning sensation in his soles and sacral areas were affected by bowel emptying. Subsequent to such evacuation the burning sensation disappeared.
- (e) In 1968 a sympathectomy was undertaken on the left-hand side for vascular ischemia; whilst this did improve the foot circulation, it made no effect on his burning sensation in his left leg.
- (f) At the level of his neurological deficit (L₁) he always noted an area of hyperesthesia. In provoking such hyperesthesia this usually gave him peculiar sensations in his feet.

Present clinical examination showed still complete somatic paraplegia, but forced deep pressure in the sole of the foot enabled him to give an indication of position. Such burning sensory manifestation has been of great help to this man in overcoming the problem of pressure and being certain where his feet are in work activities. He therefore has no pressure problems at all and has used this sensation very adequately over a period of time.

Such is the type of clinical case paper which has been noted in this review. The development of this sensory manifestation occurred over a long period of time. These observations have been confirmed by *two observers*, for it is possible at any one time for olfactory, visual and auditory sensations to interfere and made the observations difficult to be accurate.

Another example.

G. L., male, age 18, admitted 1968. Fracture dislocation C₅ on C₆ with complete tetraplegia below the level of C₆. Loss of posterior column and spino-thalamic sensation has remained complete over the period of eight years subsequent to his injury. Two to

three years after his injury he noticed that he developed a lot of unpleasant burning sensations in areas below the level of his injury. He also noted some manifestation of hyperreflexia, *e.g.* hyperhidrosis. Over a period of time he has learnt to use this unpleasant burning sensation, *e.g.* he notes on sitting for long periods of time it is aggravated. On toilet treatment he finds it is worse. As he lifts from a sitting position the burning sensation is aggravated for a moment then quickly settles down.

An interesting sensory phenomenon occurs with stimulation of the lateral aspect of his forearm. (Here he has retained posterior column and spino-thalamic sensation.) This causes him rectal irritation, with feeling of need to defaecate. Posture has also been helped by the particular ischial sensation, for he has noticed that by changing his posture the burning sensation will alter and he also experiences priapism. This young man also has a scar on the sole of his foot which he could not see but can localise. He noticed that this localisation was likely to be potentiated by other stimulation, *e.g.* recently having to have haemorrhoids operated on or secondly when his bladder is full.

Comment

Over a long period of time, such sensations, not well localised but definitely present, particularly in the ischial, rectal and perineum areas, have been of use to this man, for it has enabled and assisted him in his mode of living and his continuing habilitation activities. He has not been seen at the ordinary clinic for complications such as urinary tract infection and pressure for many years.

In an attempt to summarize the observations on the 17 patients, a table has now been prepared.

Table VII
Late neurological sequelae of spinal cord injury

Total 17	Ischial sense 16	Visceral sense 14	Sex 11	Other 15	Stereognosis 15
		(3 bladder only)		<i>e.g.</i> J. A., male T11 Rubbing right costal margin = feeling in heel	
One patient no late sensory response at all (he was also deaf)					

Of these 17 cases only one did not have the sensation of ischial burning. All but two had a sensation of bladder fullness, whilst all except two had peculiar sensory manifestations with some localisation in the feet, ankles or ischial areas. Fifteen of the 17 had peculiar sensory manifestations on stimulation above the level of the lesion causing sensory phenomena below the level of the lesion. These were in 11, sexual in nature. Whilst utilisation of this sensation had resulted in better function, no cases of stimulation below the level of damage causing afferent feeling above the level were experienced.

An example of bifid sensation:

J. A., female, age 35. Paraplegic U.M.N. T11, experienced peculiar pins and needles in the heel of her right foot on scratching the right costal margin.

I. D., male, age 30. U.M.N. T5, experienced peculiar sensations in the perineum on pinching the right nipple.

Four patients noted peculiar sensation in the lower limbs during intercourse, whilst 17 patients noted improvement in postural sensation over a period of time. This is of course a manifestation well known already in the neurological observation of most paraplegics whether they be incomplete or complete. All of these patients indicated that these sensations, particularly this burning sensation or a sense of fullness in the viscera were of great use to them in their day-to-day activities. All indicated that they had had little instruction or repetitive activity in learning how to use such phenomena. They had observed these matters for themselves and had not had general instruction in sensory recovery or sensory manifestation. All of these cases complete at the moment of their accident, have remained complete on somatic nervous system examination.

How then are these people effectively receiving these sensory stimuli? The peripheral or primary axon, the secondary axon and its nerve cell body by anatomical definition and study, by their injury, must be interfered with, particularly the secondary axon. This leaves as alternative pathways either:

- a The visceral afferent travelling in the autonomic system.
- b Afferents travelling by the plexi around the vascular tree.
- c Unsuspected but intact fibres crossing the damaged area.

In a post-mortem series studied with Kakulas, one case was examined complete on admission and so for many months, but who then developed some sensation. At autopsy intact fibres were found bridging the gap in the cord. Such fibres were considered to be a regenerative phenomenon either by the nerve roots or from the tracts. One case in this clinical series manifests good (S3-S4) sensation years after complete clinical division.

Sensory stimuli may use the afferent parasympathic and afferent sympathetic systems that are well known. Very few of such messages normally penetrate to the conscious level excluding perhaps smell and taste. Autonomic sensory nerve endings are much the same as elsewhere. Fibres from such visceral end organs are indistinguishable from somatic counterparts.

It is usually stated that visceral afferent nerve fibres have their cells stationed in either the cranial nerve sensory ganglia or the dorsal root ganglia, similar to those of the somatic afferents. It is usually said that their central continuations with the secondary cell stations are standard in form, with reflex manifestations at spinal cord level being their most important function. Thus Guttmann (1963) could report the rapid return of many visceral reflex functions, in the spinal cord after complete division or complete dehiscence of the cord. Undoubtedly many of the primary visceral afferent axones travel via the chain or synapse in the ganglia of the autonomic chain and then to axones in the dorsal horn neurones with secondary axones passing up the ordinary tracts. Such will mediate most of the conscious visceral sensations. It was noted many years ago by the present author that visceral afferents (in fact white rami communicates) could enter the spinal cord in the cervical area over a range of three or four segments. Sunderland and Bedbrook (1949).

Thus in the complete paraplegic it is possible that anatomical pathways exist via the sympathetic chain, major vessels or major ganglionated plexi conveying visceral afferent stimuli across the level of destruction or dehiscence of the cord to a level of above the cord where they can enter. In talking to Guttmann personally about the physiology of the spinal cord injury, he has expressed an opinion that some spinal fibres may take over the function of others in the incomplete spinal cord lesion. If this is so it is possible, almost probable, that afferent fibres

in the sympathetic chain may act as a bridge across the level of the spinal cord section.

Paul Bach-Y-Rita (1972) in talking about plasticity in the nervous system indicated that the central nervous system has an amazing capacity to compensate for loss and that it is capable of adapting to new classes of functional demands in a given sensory system. This is particularly so in visual sensation, but it is not unknown elsewhere. Sensory plasticity (according to Bach-Y-Rita) is the ability of one sensory system (receptors, afferent pathways, and central nervous system representation) to assume the functions of another system. Impairment on one such sensory channel will lead to a greater use of other channels and to a greater cerebral development. Bach-Y-Rita showed this well in his work on sight. White and Sweet (1955) comment on the return of pain after a cordotomy, indicating that it represents nature's remarkable ability to compensate by developing the capacity of other sensory fibres to transmit a crude form of pain and to a lesser degree other sensations such as thermal. Observations have been made by these authors on the capacity of highly differentiated areas, such as the pyramidal tract to show great recovery. Here it would appear that the effect on training and thus motivation are principal factors in at least some of this plasticity. Guttmann (1953) talked about this as early as 1953, and indicated that this would result in a new pattern of innervation. Wynn Parry (1975) in talking about sensory rehabilitation indicated that there was still a great deal of controversy as to the exact means by which information can be conveyed from the periphery to the central nervous system. It is possible that the sensory receptors may respond to more than one type of environmental energy as discussed by Melzak and Wall (1962).

The spinal cord is of course the main peripheral and preferred pathway from the periphery to the central nervous system for all kinds of information. However, in the absence of the spinal cord other pathways may then take predominance and precedence. Wall (1962) has emphasised that stimuli might be divided into two types. Those which are passively impressed on an area of skin, and those that require an active motor exploration for their discrimination. This latter would of course be relevant to the motor sensory stimulation that a paraplegic receives in their active physical rehabilitation. Such is highly developed in sporting activities as observed in games for paralysed people. Melzak (1962) proceeds to say that a stimulus which is passively impressed upon a person is a rarity in normal life, whilst the second, that associated with movement is much more common. In this group of 17 people it was a 'passive' impressing of sensation which led to the development of this burning sensation which appears to be mediated by other pathways than the spinal cord, and which has reached a conscious level over a long period of time. Yet it is now apparent that free movement is a much more important 'stress' than realised, so that passive impression is relative.

It is clear from the study of these 17 patients that the efficiency with which each of these people will use a sensory stimulus is quite different: at least one of the people examined indicated that no stimuli were getting through to conscious level, even though this man by all standards was well rehabilitated. The subjective effect of such impulses relates to the learning process, this of course depends on the central nervous system developing a decoding mechanism which will sort out the various categories of the sensations experienced. Undoubtedly in these particular 17 patients the process of ischemia or the pathological process of stress is getting sensation through to conscious level. This can be done by either: (a) Chemical means, (b) Afferent means as above and (c) Anatomical pathways as yet unknown.

The application of information from such patients as these should be applicable to: (a) incomplete cases and (b) complete cases.

It is apparent from the study of the 17 patients and the theoretical considerations on how these sensations reach the conscious level that not enough time is spent on our rehabilitative processes to effectively develop the well-known sensory phenomenon of facilitation. This is well developed in paraplegic management in relationship to the upper motor neurone bladder and developing a trigger point. It is not well recognised that sensory stimuli, e.g. from the respiratory tract, will help occasionally in the development of sensation (whether this is useful or not) in the sole of the foot. Undoubtedly in repetitive activities involving both the motor and sensory side, e.g. sport, such sensation using both touch and hand movements will go far in the incomplete cases in redeveloping sensory pathways if the theory of plasticity is well applied. In complete cases, more attention to the use of passive stimulation such as pressure and temperature, providing this is not to the stage of burning, will be perhaps of more use to the patient in the future than it has in the past. Observations on the present very small pilot series indicate that such function should be much better used in the future than it has been, or is being used, at the present time.

SUMMARY

Sixty-five per cent of cervical dorsal injuries with neurological change will be incomplete on admission whilst 5 to 50 per cent lumbo dorsal neurological injury will manifest root sparing. The presence of such neurological incompleteness improves the prognosis. Results of long-term neurological examination and observation and their application over a period of years are less well known.

Over a period of 22 years subsequent to the establishment of the Spinal Paralysis Unit in Perth, Western Australia, a small series of 17 cases originally admitted to hospital with complete paraplegia or tetraplegia (and substantiated by clinical examination on admission and discharge initially) showed interesting clinical change over a 10 to 15 years observation period. These changes are only sensory: (a) Improvement in somatic function, (b) Improvement in autonomic function.

Such improvement resulted in patients having sensation at a useful level, although no real attempt had been made to develop this sensation over a period of time. In no case was long-term motor recovery noted of use. Careful regular monitoring of neurological dysfunction is of value. Repeated stimuli of many types should be used in the treatment to improve sensory function. Rehabilitation of sensory function is of much more importance than has been hitherto discussed.

REFERENCES

- BEDBROOK, G. M. & KAKULAS, B. A. (1969). A correlative clinic-pathology study of spinal cord injuries. *Proc. Aust. Assoc. Neurol.* **6**, 123-132.
- BACH-Y-RITA, P. (1972). *Brain Mechanisms in Sensory Substitution*. Academic Press, New York & London.
- BURKE, D. C. & MURRAY, D. D. (1976). The management of thoracic and thoraco-lumbar injuries of the spine with neurological involvement. *J. Bone Jt Surg.*, **1**, **58B**, 72-78.
- FRANKEL, H. L., HANCOCK, D., HYSLOP, G., MELZAK, J., MICHAELIS, L., UNGAR, G., VERNON, J. & WALSH, J. J. (1969). The value of postural reduction in the initial management of closed injuries of the spine with paraplegia and tetraplegia. *Paraplegia*, **7**, 179-192.

- FRANKEL, H. L. (1969). Ascending cord lesions in the early stages following spinal injury. *Paraplegia*, **7**, 111-116.
- GUTTMANN, L. (1953). Principals of reconditioning severely injured man with particular reference to paraplegics. *A Symposium on Stress conducted by the Army Medical Service Graduate School*: 246-260. The U.S. Government Printing Service, Washington, D.C.
- GUTTMANN, L. (1963). *Proceeding of symposium on spinal injuries*, edited P. Harris. Royal College of Surgeons of Edinburgh, 80-92.
- HEAD, H. (1920). *Studies of Neurology*, **1**, 396-508. Oxford Medical Publications.
- HUGHES (1851). *Lancet, London*, **2**, 131 (discussion only).
- MELZAK, R. & WALL, P. D. (1962). On the nature of cutaneous sensory mechanisms. *Brain*, **85**, 353.
- MUNRO, D. (1943). Thoracic and lumbo-sacral cord injuries. *J. Amer. Med. Assoc.*, **122**, 1055.
- OSTERHOLM, M. D. (1974). The pathophysiological response to spinal cord injury. *J. Neurosurg.*, **40**, 5-33.
- SCHNEIDER, R. (1956). Chronic neurological sequelae of acute trauma to the spine and spinal cord. *J. Bone & Joint Surg.*, **5**, 3, 985.
- SUNDERLAND, S. & BEDBROOK, G. M. (1949). The relative sympathetic contribution to individual roots of the brachial plexus in man. *Brain*, **72**, 297.
- WHITE, J. E. & SWEET, W. H. (1955). *Its mechanisms and neurosurgical control*. Springfield, Charles C. Thomas, 736.
- WOLMAN, L. (1964). The neuropathology of traumatic paraplegia. A critical historical review. *Paraplegia*, **1**, 237-251.
- WYNN-PARRY, C. B. (1975). Rehabilitation of upper limb injuries. *Rehabilitation Medical Conference, Perth, Western Australia*.