

■ SPINE

Traumatic spinal cord and cauda equina injuries

A COMPARISON OF NEUROLOGICAL OUTCOMES ACHIEVED BY A 75-YEAR-OLD SYSTEM OF MANAGEMENT, AND MODERN CARE IN THE USA

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Aims

The aim of this study was to compare neurological outcomes achieved by two systems of spinal cord injury care: that which was developed by the National Spinal Injuries Centre, Stoke Mandeville Hospital, UK (predominantly conservative, 10% to 15% treated with surgical stabilization, most with gradual mobilization) and that which is practised by USA centres contributing data to the Spinal Cord Injury Model Systems (SCIMS) database (predominantly surgical, often > 80% undergoing surgical stabilization, most with rapid mobilization).

Methods

Neurological outcomes from 608 patients treated at Stoke Mandeville between 1951 and 1968, and 300 patients treated using the Stoke Mandeville system at Colmar-Mulhouse and Basel (France and Switzerland) between 1968 and 1978, were compared with 804 patients admitted to SCIMS rehabilitation centres between 2011 and 2018. The stratified Mann-Whitney U test was used for overall neurological outcomes; subgroups were tested for differences in proportions.

Results

Both Stoke Mandeville system centres achieved significantly better Frankel grade neurological outcomes compared with SCIMS centres (Stoke Mandeville, $p < 0.001$; Colmar-Mulhouse and Basel, $p < 0.001$). Had the 804 patients treated at SCIMS centres in the USA achieved the outcomes which were achieved using the Stoke Mandeville system, between 71 and 87 fewer might have deteriorated neurologically, between 195 and 330 more patients might have walked again, and between 129 and 264 more patients might have been completely cured, with no sensory or motor loss and no sphincter disturbance.

Conclusion

The Stoke Mandeville system of spinal cord injury care should not have been rejected without clinical trials.

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Introduction

This paper compares two systems of care for patients with a spinal cord injury. One was developed by Sir Ludwig Guttmann, a neurosurgeon, and others at the National Spinal Injuries Centre, Stoke Mandeville Hospital (UK), with input from other spinal cord injury centres. It was based on the consistent observation that conservative management of the injured spine produced better neurological and other outcomes than surgical management. The other system encompasses Spi-

nal Cord Injury Model Systems (SCIMS) centres in the USA. Participating centres receive federal funds for research. A total of 32 centres have contributed to a national spinal cord injury database; about half that number contribute in any one year.

The Stoke Mandeville system is an elaborate system of care comprising several elements, each helping to promote natural healing through the recovery of dormant motor neurones. Natural healing was historically observed even when spinal architecture was severely damaged. Con-

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Table I. Frankel classification.

Grade	Description
Grade A, "complete"	Complete motor and sensory loss below the level of the lesion.*
Grade B, "sensory only"	Some sensation present below the level of the lesion, motor paralysis complete below that level.
Grade C, "motor useless"	Some motor power present below the lesion, but of no practical use to the patient.
Grade D, "motor useful"	Useful motor power below the level of the lesion. Patients in this group could move lower limbs and many could walk, with or without aids.
Grade E, "recovery"	Patient free of neurological symptoms, i.e. no weakness, no sensory loss, no sphincter disturbance.

*The neurological level of injury was the last normal segment below which usually three but occasionally four, or even five segments (zone of partial preservation (zpp)) exhibit some impaired or abnormal sensation and/or motor activity. Below the zpp, there is no motor or sensory activity.

siderable energy is spent on impacting bony and ligamentous structures, reducing the energy available to damage the spinal cord. The lack of correlation between the severity of the injury on radiographs and neurological presentation was subsequently confirmed with CT and MRI.^{1,2}

External supports including braces, pillows, and sandbags were used in an attempt to realign the injured spine and contain biomechanical instability. Patients were nursed flat to prevent further neurological and non-neurological damage during the period of time when both the sympathetic and spinal reflexes were absent.

Care was provided to stabilize the physiology of every bodily system deprived of normal higher nervous system regulation, preventing complications which might further damage the spinal cord. The respiratory system was treated to prevent infections and respiratory failure, both of which can cause low levels of oxygen in the blood. The circulatory system was treated to prevent severe bradycardia and significant hypo- and hypertension. Patients were turned every two to three hours, day and night, to prevent pressure sores and generalized sepsis, and to ensure postural drainage of the lungs. Assisted coughing was provided to clear the bronchi, and mitigate the development of pneumonia and the need for ventilation and intensive care. The bladder was intermittently catheterized to drain urine. This minimized the risk of infection, helped to maintain the elasticity of the bladder wall, prevented the development of urinary calculi, protected the upper urinary tract, and helped to prevent generalized sepsis and renal failure. The bowels were regularly manually evacuated and aperients prescribed to prevent severe constipation and autonomic dysreflexia.

Following up to 12 weeks in recumbency to achieve biomechanical stability of the fractured spine, patients began 'monitored mobilization after physiological stabilization'. The weeks in bed were considered to be crucial. Mobilization was delayed until after the recovery of autonomic and somatic reflex activity. This helped ensure blood pressure and oxygen levels were sufficiently stabilized to maintain perfusion pressure and preserve physiologically compromised and vulnerable nerve tissues. Lying the patient flat allowed carers to provide effective assisted coughing and help them clear their lungs of secretions, significantly reducing the need for ventilation which, once started, proved difficult to withdraw. Nursing flat minimized the risk of pressure sores over the ischial, sacral, coccygeal, and posterior trochanteric bony tuberosities during the stage of absent or poor vasomotor activity and poor skin perfusion. The risks of lower limb oedema, deep vein thrombosis, and pulmonary embolism were reduced. Regularly positioning the patient

in the crucifix position with the legs straight and apart made it possible to avoid disabling flexion contractures of the shoulders, elbows, and knees, as well as contractures of the flexors and adductors of the hips.

Rehabilitation began much earlier than mobilization. Patients were educated about their condition and on how to avoid complications. They met fellow patients striving to achieve independence and effective self-care, and patients living at home but returning for follow-up review. Peer support from patients who had succeeded for many years following injury gave hope to the newly injured. They discussed work, holidays, and even participation in the international sports which evolved into the Paralympics. Encouragement, optimism, and high expectations were promoted as rigorously as the nursing mantra 'skin, bladder, and bowels'.

From the 1980s onward, two major developments in the Stoke Mandeville system of care emerged among leading centres. It was found possible, by stabilizing the fracture with external bracing, to reduce the initial period of bed rest to between four and eight weeks, provided that autonomic and spinal reflexes had fully returned by then. Patients' motor power, sensation, reflexes, blood pressure, vital capacity, and oximetry were monitored while they were gradually mobilized. A second development was an improved identification of those who might benefit from surgical (rather than postural) reduction and stabilization of their spinal fracture(s), generally between 10% and 15% of spinal cord injury patients. These groups included uncontrolled epileptics, patients with psychiatric conditions, patients (with and without neurological damage) who were unable to comply with bed rest, patients with ligamentous injuries without bony injury (at risk of late painful deformities), and patients with neurological deterioration and loss of pre-existing sensory sparing which, radiologically, was thought to be due to progressive spinal cord compression.

In the USA, rather than using postural reduction and natural bony healing to restore biomechanical stability, most patients with a spinal cord injury underwent surgical reduction and stabilization, with or without decompression of the neural tissues. Surgery was generally performed in acute care services before transfer to a spinal cord injury centre. This system was developed in the belief that stabilization reduced the risk of further mechanical damage from displacement of the fracture(s), reduced the demands on nurses and orderlies, and allowed an earlier completion of rehabilitation.

In 1969, Frankel et al³ reported the neurological (strictly neurofunctional) outcomes for a large series of patients with a spinal cord injury, whose motor power, sensation, and reflexes

Table II. Neurological outcomes of patients with spinal cord injury.

Frankel grade on admission	Frankel grade at discharge*				
	A	B	C	D	E
Stoke Mandeville spinal cord injury outcome data (n = 608)					
A	301	45	14	32	1
B	4	19	7	36	9
C	1	1	10	31	9
D	0	0	0	54	34
Colmar-Mulhouse and Basel outcome data (n = 300)					
A	113	25	11	7	2
B	0	5	10	23	13
C	0	0	5	50	20
D	0	0	0	3	13
SCIMS spinal cord injury outcome data (n = 804)					
A	137	49	31	9	1
B	34	68	49	22	0
C	14	26	31	116	0
D	6	6	2	195	8

*For the SCIMS spinal cord injury outcome data, follow-up Frankel grades were recorded at one year.
SCIMS, Spinal Cord Injury Model Systems.

were documented as recommended by the Medical Research Council. All these patients were treated at the National Spinal Injuries Centre, Stoke Mandeville between 1951 and 1968. They were graded on admission and discharge, according to key aspects of their neurological status in the Frankel classification (Table I).

Frankel based his grading system on groups of patients who, he observed, had a similar likelihood of recovering useful neurological function. He realized that only a sparse dataset was required. For example, while the neurological level of injury might temporarily change by one or two segments, this did not result in neurological changes distal to that level. Therefore, changes in the neurological level of injury were not included in his grading system.

This Frankel classification gained international popularity and was adopted by the standards committee of the American Spinal Injury Association (ASIA) in 1982.⁴ In 1990, ASIA, partly to improve interobserver reliability, redefined the zone of partial preservation, limiting it to three segments below the neurological level of injury.⁵ Waters et al,⁶ in 1991, found that this change meant that six of 445 patients with a traumatic cord injury were recorded as deteriorating from incomplete to complete, when Frankel would have graded them A (complete injury) on both initial examination and at follow-up, i.e. it introduced a false-positive deterioration in approximately 1.3% (6/445). They also analyzed the impact of using a 'sacral sparing' definition to determine the completeness of the injury. Here, complete injury is defined as 'no sensory and/or motor function at the sacral segments'. Waters et al⁶ concluded that the sacral sparing criterion for complete injury was more 'stable' than the Frankel system. It recorded more 'unidirectional neurological change' from complete to incomplete status, and fewer 'bidirectional neurological changes', which included clinical deterioration.

The sacral sparing grading system was adopted by ASIA in 1992.⁷ Grades D and E remained unchanged, but grades A to C were linked to more demanding criteria: sensation and motor

power in the lowest part of the cord, sacral spinal segments S4 to S5. The new sacral sparing grading system resulted in many patients with previously incomplete injuries of Frankel grades B and C being reclassified as complete ASIA grade A on admission. For these patients, no further deterioration of grade could be documented. Although there was no improvement in the quality of care which was provided, nor improvements in the physical condition of patients after treatment, the new sacral sparing-dependent grades recorded many fewer deteriorations.⁸

From 1992, spinal cord injury centres in the USA stopped allocating Frankel grades and adopted sacral sparing grades. This change was endorsed internationally and thus, from 1992, it became impossible to compare the outcome in the USA with Frankel outcome data.

The 1992 grading system has been further modified several times. New versions were published in 1996, 2000, 2011, 2015, and 2019. It became even more difficult to compare outcomes between different spinal cord injury centres because grading practice changed so often, and because all ASIA versions after 1992 differed so dramatically from the Frankel system.

We recently became aware that Kirshblum et al⁸ used patients' records from the SCIMS Study database to retrospectively allocate Frankel grades on admission and follow-up to 804 patients admitted to USA spinal cord injury rehabilitation centres between 2011 and 2018. This was done as part of a study comparing the diagnostic stability of different classification systems for traumatic spinal cord injury. Outcomes for each patient were thus reported twice, once according to the sacral sparing-based system, and once according to the Frankel system.⁵ With this breakthrough, it became possible to compare outcomes in terms of Frankel grades over the very considerable period 1951 to 2018, which was thus the aim of this study.

Methods

Two studies were selected to represent the Stoke Mandeville system.^{3,9} These studies were large. No patients (or few patients) had spinal surgery, and the injuries involved all spinal levels.

The leading clinicians had worked at Stoke Mandeville, trained there, or made study visits.

In the first study, 608 patients had closed spinal injuries and were admitted within 14 days of injury between 1951 and 1968. The patients were graded Frankel A to D on admission (indicating some neurological deficit) and Frankel grades A to E on discharge.³

Second, in 1980, Philippi et al⁹ reported the outcomes for 300 patients at cooperating hospitals in Colmar-Mulhouse and Basel between 1968 and 1978. All were admitted within 24 hours of injury, much sooner than at Stoke Mandeville. The authors acknowledged they had applied 'very strict' indications for surgery; 27 patients (9%) had surgery.

Kirshblum et al⁸ analyzed 804 patients admitted to USA spinal cord injury rehabilitation centres between 2011 and 2018. All had sustained a traumatic spinal cord injury and were aged > 15 years. They were admitted for rehabilitation within 30 days of injury. The proportion treated surgically was not reported.

It is important to bear in mind factors which might influence outcomes in these studies. It is unusual to compare outcomes achieved over such a long period of time (1951 to 2018).

It is likely that most patients excluded from the various study groups had inadequate notes and radiographs which were available from admission and discharge. In the Stoke Mandeville study, patients who were treated surgically were excluded. The focus of the study was to examine neurological progress after postural reduction and conservative management. Studies with unusual exclusion criteria were rejected from this analysis, such as a study in which patients with cervical C1 to C2 lesions were excluded from analysis, or studies in which patients with injuries at specific spinal levels, such as those with cervical spinal injuries only, were included.

At the National Spinal Injuries Centre, Stoke Mandeville, 218 patients (36%) had a cervical spinal cord injury,³ at Colmar-Mulhouse and Basel, 108 patients (36%).⁹ In the SCIMS sample, 453 patients (56%) had cervical spinal cord injuries.⁸ Cervical spinal cord injuries are reputed to have slightly better outcomes than injuries to the lower spine because the cervical canal is wider and the cervical blood supply better. Therefore, SCIMS centres would be expected to have had better outcomes.

The Frankel grade on admission to a spinal cord injury centre was compared to a later outcome: the Frankel grade either at discharge (Stoke Mandeville, Colmar-Mulhouse and Basel) or at one year after injury (SCIMS). In most cases, discharge from the National Spinal Injuries Centre in Stoke Mandeville took place at about one year after admission; patients remained in hospital for several months after completion of medical treatment until suitable housing became available in the community. At Colmar-Mulhouse and Basel, the length of stay in the rehabilitation centres averaged about six months for paraplegics, and between nine and 12 months for tetraplegics.

Frankel et al³ did not include a numerical figure for the minimum MRC grade motor power required to achieve grade D in their classification. In practice, patients with power three ('Active movement against gravity without resistance') or four were documented as Frankel D. MRC grade 5 was required to achieve grade E. Patients with some motor power, but with the majority of muscles with power less than power three, were

documented as being Frankel C. These Frankel categories were not amended in their ASIA counterpart classification, but helpfully the definitions were made more explicit.

During the 50 years between the studies which are being compared, many improvements were made in surgical and rehabilitation practice, in beds, catheters, antibiotics, and other drugs. Such advances would be expected to give better outcomes in the SCIMS centres.

Patients with a clinical loss of neurology suffer not only the loss of function itself, but also the opportunity for natural healing, improved neurology, bodily system safety and functions, and independence.

Statistical analysis. The stratified Mann-Whitney U test was used for overall neurological outcomes; subgroups were tested for differences in proportions. R v. 2024 (R Foundation for Statistical Computing, Austria) was used.^{10,11} A p-value < 0.05 was considered significant.

Results

Table II shows Frankel grades on admission and follow-up at the three spinal cord injury centres.

The stratified Mann-Whitney U test was used to compare the SCIMS series outcomes with those from each of the centres using the Stoke Mandeville system of care. Taking patients of all initial Frankel grades together, both Stoke Mandeville system centres achieved significantly better outcomes compared with the SCIMS centres (Stoke Mandeville, $p < 0.001$; Colmar-Mulhouse and Basel, $p < 0.001$).

In order to improve our understanding of the strongly significant Mann-Whitney U test results, important subgroups were tested for significance using the one-sided test for differences in proportions (Table III). Some tranches were not large enough to allow firm conclusions in isolation, but the results taken together provide clinical insights. In some cases, statistical tests suggest one system was clearly better. In other subgroups, the results are at the borderline of significance, probably due to smaller effect differences in those categories, or small datasets.

Results from the Stoke Mandeville system centres were not aggregated because during the period from 1951 to 1978, medical knowledge, equipment and available medications all advanced greatly, making Colmar-Mulhouse and Basel outcomes superior to Stoke Mandeville outcomes. Furthermore, Colmar-Mulhouse and Basel admitted all their patients within 24 hours allowing Stoke Mandeville system care to be provided soon after injury.

Among patients initially graded B to D, deterioration to a lower neurological grade was significantly less likely at Stoke Mandeville system centres. Neurological deteriorations affect all bodily systems deprived of higher nervous system control, and functional recovery.

It is especially valuable for patients to achieve a 'motor useful' outcome of grade D (useful motor power below the level of the lesion, many being able to stand and walk) or E (complete recovery, including sphincter functions). Grade D is a wide band, and includes patients who can walk without support, require walking sticks, crutches, orthoses, and few who intermittently use a wheelchair. Grade E remains the golden prize.

Table III. Important patient outcomes: deteriorations, motor useful improvements, and complete recoveries.

Initial Frankel Grade	Stoke Mandeville, n/d (%)	Colmar-Mulhouse and Basel, n/d (%)	SCIMS, n/d (%)	p-value*	
				Stoke Mandeville vs SCIMS	Colmar-Mulhouse and Basel vs SCIMS
Patients	608	300	804		
Deterioration to lower Frankel Grade					
B	4/75 (5)	0/51 (0)	34/173 (20)	0.004†	< 0.001†
C	2/52 (4)	0/75 (0)	40/187 (21)	0.003†	< 0.001†
D	0/88 (0)	0/16 (0)	14/217 (6)	0.016‡	ID
Motor useful improvement to Frankel Grade D or E					
A	33/393 (8)	9/158 (6)	10/277 (4)	0.043‡	0.368
B	45/75 (60)	36/51 (71)	22/173 (13)	< 0.001†	< 0.001†
C	40/52 (77)	70/75 (93)	116/187 (62)	0.034‡	< 0.001†
Complete recovery, improvement to Frankel Grade E					
A	1/393 (0)	2/158 (1)	1/227 (0)	ID	ID
B	9/75 (12)	13/51 (25)	0/173 (0)	< 0.001†	< 0.001†
C	9/52 (17)	20/75 (27)	0/187 (0)	< 0.001†	< 0.001†
D	34/88 (39)	13/16 (81)	8/217 (4)	< 0.001†	< 0.001†

*Mann-Whitney U test.

†Significant at 1% level.

‡Significant at 5% level.

d, denominator; ID, insufficient data; n, numerator; SCIMS, Spinal Cord Injury Model Systems.

Table IV. Important patient outcomes: summary.

Variable	SCIMS results		
	Actual	If Stoke Mandeville outcomes achieved	If Colmar-Mulhouse and Basel outcomes achieved
Patients experiencing a Frankel grade deterioration, n	87*	16	0
Patients experiencing motor useful improvement, n†	156	351	486
Patients experiencing complete recovery, n‡	9	138	273

*1.3% correction for 'false-negative' clinical deteriorations.

† Grades A to C to Grades D to E, and Grade D to Grade E.

‡ Grades A to D to Grade E.

The Stoke Mandeville system centres achieved significantly more complete recoveries (grade E) than were achieved in SCIMS centres in the USA.

Discussion

The Stoke Mandeville system and the Frankel classification are now seen as old-fashioned ways to assess and treat patients with a spinal cord injury. Hospitals are incentivized to undertake spinal surgery in order to achieve rapid stabilization to encourage rapid mobilization and early discharge. The Stoke Mandeville system was abandoned without evidence or clinical trials to ascertain superiority or at least equality of neurological outcomes.

In the UK, the trend towards early surgery and rapid mobilization spread rapidly after spinal cord injury was abolished as a distinct medical speciality. Entry into the European Union was associated with a harmonized list of medical and surgical specialties. Specialist training in spinal injuries in the UK was significantly reduced in duration and subsumed into general rehabilitation; care became fragmented between trauma centres, district hospitals, and spinal injury centres. Frankel grade outcomes are no longer recorded having been replaced by ASIA

sacral sparing-based systems of classification, without necessarily identifying which revision is being used. Neurological outcome data are collected, but no analyses have been published and the national database is unavailable outside the NHS.

Despite old-fashioned treatment, patients at Stoke Mandeville system centres between 1951 and 1978 achieved better outcomes than for those treated at SCIMS centres between 2011 and 2018. Patients treated at Colmar-Mulhouse and Basel between 1968 and 1978 had better outcomes than those treated at Stoke Mandeville system centres between 1951 and 1968. Results from other Stoke Mandeville system centres suggest continued improvements. Bedbrook and Sakae,¹² in 1982, in a study from Perth, Australia, which included 56 patients with a grade D cervical spinal injury, reported that 48 (86%) recovered to grade E. A 2014 study from Nnadi and Bankole¹³ in Calabar, Nigeria, found that 100% of 25 grade D patients recovered to grade E. Both centres used the Stoke Mandeville system. The rate of surgery was 10% (15/144) in Perth, and 0% (0/76) in Calabar; both centres received patients very soon after injury. Patients in Calabar were brought straight to the hospital. Overall, 84% of 144 patients in Perth were transferred to the spinal injury unit within 24 hours of injury; 30% were transferred

within three hours. The Perth paper was not included in this analysis because all the patients had cervical injuries. The Calabar paper was also not included, as it was not clear which version of the Frankel/ASIA system was used; this would affect patients graded A to C, but not patients graded D and E.

The later the cases were reported, the more their care was informed by accumulating medical knowledge and advances in equipment, technology and pharmaceuticals. This again would have favoured those treated at SCIMS centres.

Despite these advantages, the number who suffered neurological deterioration among 804 SCIMS patients (after correcting for possible 'false-negative' deteriorations) was between 71 and 87 more than might have occurred at Stoke Mandeville system centres (Table IV). Similarly, had Stoke Mandeville system levels of improvement been achieved in these 804 patients, between 195 and 330 more might have become able to walk in some manner, and between 129 and 264 more patients might have recovered completely (only nine complete recoveries were actually achieved).

It is unusual to observe differences of such magnitude in a comparative medical study.

Kirshblum et al⁸ provided the first large body of modern outcome data from the USA which can be compared with data from Stoke Mandeville system centres. The inferior outcomes observed make it essential that other datasets are published and compared. In this age of evidence-based medicine, there is a moral duty on service providers and medical academics to provide the evidence required for clinicians, patients, relatives, hospital managers, insurers, and legal advisers to make informed choices.

If outcomes are to improve, systems of care need to change. Until they do, the past stands as a reproach to the present.



Take home message

- The Spinal Cord Injury Model Systems system of care has recently spread almost worldwide.
- All centres practising this system should publish neurological outcome data in a form that allows comparison with Stoke Mandeville system outcomes.

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