SPINAL CORD INJURY IN CHILDREN AND ADOLESCENTS: DIAGNOSTIC PITFALLS AND THERAPEUTIC CONSIDERATIONS IN THE ACUTE STAGE

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Abstract. Traumatic spinal cord lesions in children are infrequent. Traffic accidents are responsible for at least 50 per cent, playground accidents and various sports add another 35 per cent. Radiological signs of spinal trauma are less evident than in adults, they may be missing totally. In the initial treatment of spinal cord injury, only conservative measures should be considered, there are no indications for laminectomy or spinal fusions.

Key words: Paraplegia in childhood; Birth trauma; Intensive care; Anticoagulation.

Introduction

INITIAL care and future rehabilitation of the paraplegic child and adolescent rely essentially on the same well-established rules and principles which have been clearly defined over the past quarter-century for adult patients; correct initial transport under medical supervision, immediate hospitalisation in a paraplegic centre rather than in a general pediatric hospital, conservative fracture treatment (*i.e.* practically no fusions nor laminectomies), continuous monitoring of respiratory and cardiovascular functions, regular body rotations, physiotherapy, etc.

As one approaches the acutely injured child there arise, however, several problems, both concerning diagnosis and treatment, that require thorough experience in pediatric radiology, intensive-care and, last but not least, child psychology (Babcock, 1975; Campbell, 1975).

In the chronic stage, development of progressive spinal deformity in the young paraplegic child requires sound understanding of the particular anatomomorphological changes that occur in the spine during growth, as well as of the ultimate biomechanical consequences of the sustained vertebral injury (Hemmer, 1970; Griffiths, 1974; Hubbard, 1974).

Since spinal cord lesions in childhood are relatively rare, we may not always be aware of certain diagnostic pitfalls and medical emergency situations, especially in the infant and young child. Although our own personal experience, based on the analysis of 18 case-records is quite modest, we wish to draw our colleagues' attention to some commonly encountered problems and risk situations which we have met repeatedly during the acute stage.

These aspects will be dealt with after a short epidemiological review.

Frequency

Only few data have been published on epidemiological features of spinal cord lesions in infancy and childhood (Norton, 1959; Melzak, 1969; Audic, 1971;

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Meinecke, 1972; Burke, 1974; Cullen, 1975). Most authors estimate the frequency to be approximately 2 to 4 per cent. However, these ciphers only take in account those children who have been admitted to paraplegic centres. They do not reflect true incidence, since an unknown number of juvenile patients are still treated in orthopedic sections and spina bifida centres of general pediatric hospitals. Burke reported on 29 cases who had been admitted to Rancho los Amigos over a period of 18 years; Melzak analysed a group of equal size seen at Stoke Mandeville during two decades. At our own centre, 18 patients have been treated during the past 12 years (Tables I and II).

TABLE I
Traumatic spinal cord lesions in children below age 10

Case No.	Age at injury	Sex	Cause of trauma	Vertebral injury	Initial level M.	Follow-up years	Final level M.
1	Birth	M	Obstetric	No signs	L3/4 inc.	13	L5/S1 inc.
2	5	M	Gunshot	No signs	Th6/7 comp.	2	Th6/7 comp.
3	5	F	Crush injury	No signs	C5/6 comp.	3	C6/7 inc.
4	5	M	Fall 2 m.	No signs	Th8/9 comp.	14	Th8/9 comp.
5	6	M	Bicycle/car	No signs	L1/2 comp.	3	L2/3 comp.
6	6	F	Fall 10 m.	C5, C6	C6/7 comp.	4	C7/8 comp.
7	7	M	Hit by car	No signs	C5/6 comp.	16	C7/8 inc.
8	7	F	Hit by car	Comp. Th11	Th11/12 comp.	9	Th11/12 comp.
9	8	F	Hit by car	Comp. Th8	Th8/9 comp.	16	Th8/9 comp.

TABLE II
Traumatic spinal cord lesions in children between age 10 and 15

Case No.	Age at injury	Sex	Cause of trauma	Vertebral injury	Initial level M.	Follow-up years	Final level M.
10	11	M	Fall 3 m.	Th5	Th4/5 comp.	2	Th4/5 comp.
11	12	M	Gunshot	No signs	Th12/L1 inc.	2	L2/3 inc.
12	13	F	Fall 7 m.	L1, L2	L3/4 inc.	14	L5/S1 inc.
13	14	M	Electrocution	No signs	Th6/7 comp.	7	Th7/8 comp.
14	14	F	Bicycle/car	L1	L1/2 comp.	1/2	L2/3 comp.
15	14	F	Gunshot	No signs	Th12/L1 comp.	10	Th12/L1 comp.
16	15	M	Hit by car	C5	C6/7 comp.	2	C6/7 comp.
17	15	M	Diving ext.	C4, C5	C4/5 comp.	3	C4/5 comp.
18	15	F	Car passenger	Th4, Th5	Th4/5 comp.	7	Th4/5 comp.

Causes of Spinal Injury

Spinal cord trauma due to obstetric complications such as breech delivery has been well documented by Towbin (1969), Jones (1970), Shulman (1971) and De Souza (1974). Maekawa has recently observed a quite exceptional case of complete tetraplegia in a newborn female delivered by Caesarean section and who had shown marked cervical hyperextension on X-rays taken a few days prior to birth.

In the young child spinal injury is frequently caused by motor vehicle accidents (Glasauer, 1972, 1973) and playground equipment, such as climbing-frames,

TABLE III
Radiological signs of vertebral lesion

	0-10 years	10-15 years
No evidence of lesion	5	3
Slight compression (squaring)	2	2
Fracture—dislocation	1	2
Multiple fragments	1	2

TABLE IV
Final neurological level of lesion

Cervical	(C4-C8)	5 (2 comp./3 inc.)
Thoracic	(Th1-Th11)	8 (8 comp.)
Thoraco-lumbar	(Th11-L5)	5 (2 comp./3 inc.)

FIG. 1 (By courtesy of Professor M. Aufdermaur,
Pathological Institute, Luzern, Switzerland).

swings and slides. Accidents are likely to occur when older children join in with much younger ones on the same equipment (Illingworth, 1975).

Burke reported on a surprisingly high incidence of gunshot wounds (14 per cent) in Southern California. In our series of 18 cases, three lesions (two complete, one incomplete) were caused by firearms; all victims were of Italian nationality.

Radiological Findings

Radiological signs of vertebral injury are missing in more than half of the patients below age 10. Slight wedging may be observed, but flattening of the normally convex end-plates of the vertebral body are frequently the only signs of recent trauma (Horal, 1972). True fracture lines are never seen in the young child, and prior to puberty totally avulsed vertebral corners are an exception (Tables III and IV).

In two-thirds of our patients below age 10, radiological signs of vertebral trauma were entirely missing. Spinal cord injury may thus remain unrecognised, particularly in the comatous child. Occasionally upper cervical hypermobility causes minor vertebral dislocation that may mimic post-traumatic subluxation (Cattell, 1965).

Histopathological studies (Aufdermaur, 1974) indicate that the vertebral

FIG. 2

injuries are essentially confined to the cartilaginous end-plates which are split (Fig. 1). The growth-zone shows multiple fissures in the columnar cartilage. As a rule, the intervertebral discs show no tearing.

Fracture Treatment

In all our cases with closed trauma treatment has been strictly conservative. In the tetraplegic child above age 6 we apply Crutchfield traction (3 to 4 pounds) for a period of 3 weeks; thereafter the child wears a plastic collar for an additional 4 weeks (Fig. 2). In the infant and small child, the elasticity and fragile texture of the skull render traction impossible. Satisfactory immobilisation without discomfort for the child can be achieved with well-adjusted bilateral head-rests.

Initial Intensive Care

Respiratory Insufficiency

In the paraplegic child respiratory insufficiency may develop insidiously and be overlooked even by a well-trained nursing staff. It may prove difficult to determine the critical moment when the patient requires respiratory assistance. Repeated blood gas analyses provide helpful guide-lines, but are rather impractical due to the fact that the intraarterial catheter, commonly used in adults, often causes severe circulatory disturbances in the young child. Therefore direct arterial punctures are required for every assessment. In apparent oxygen deficiency one should always first try to improve ventilation.

Children experiencing difficulty in breathing get restless and often swallow considerable amounts of air; the ensuing gastric distension may markedly reduce the efficacy of diaphragmatic movements, thus aggravating the respiratory distress. After evacuation of the stomach, breathing resumes a slower and more regular pattern.

If respiratory assistance remains imperative, we first resort to naso-tracheal intubation which has the advantage of facilitating bronchial suction and allowing for easy fixation of the tube without kinking. Our patient ref. no. 16 with a complete C6-C7 tetraplegia remained intubated for 18 consecutive days without any signs of intolerance.

Whenever possible we avoid tracheotomy. If it is true that with the use of modern plastic cannulae of appropriate length and curvature most tracheostomy complications, *i.e.* tracheal perforation, mediastinal emphysema and pneumothorax can be avoided, there still remain late complications due to shrinkage of scar-tissue in areas of previous tracheal damage. When selecting a cannula, one should bear in mind that the child's trachea shows narrowing in an hour-glass fashion at the level of the cricoid cartilage. Particular care must be taken not to damage the fragile tracheal wall at that level, since this may cause marked local edema that further increases airway resistance and leads to the child's exhaustion.

Tracheo-bronchial aspiration must always be operated intermittently through a Y-tube, in order to prevent aspiration of mucosa through the catheter tip with subsequent haemorrhagic erosions.

In order to conveniently humidify the airways one should preferably administer air at body temperature and at a relative humidity of 100 per cent. In children who have become used to the low airways resistance, offered by tracheostomy, signs of respiratory insufficiency may develop when one attempts to remove the cannula after several months.

Fluid and Electrolyte Balance

Compared to an adult, the child's body contains significantly larger amounts of extracellular water and also has a more rapid turn-over of water per kg of body weight. In a post-traumatic situation, such as spinal cord injury, it is therefore particularly important to check the diuresis at regular 2-hourly intervals. This can initially only be achieved through an indwelling catheter. As a rule, we shift over to intermittent catheterization after approximately one week.

In infants and small children a sudden rise in body temperature may be the first sign of dehydration. Depending on the previous clinical history, dehydration may be either hyper- or hypotonic. Appropriate therapeutic measures should rely on repeated laboratory assessment of electrolytes, osmolality and pH. Hypertonic dehydration may occur during prolonged hyperventilation, allowing for considerable losses of fluid via the alveoli. A similar situation also arises if the kidneys are unable to concentrate urine sufficiently. Hyperhydration may be followed by hypotonic dehydration. This situation develops after repeated administration of enemas and loss of electrolytes in the course of multiple gastric flushings with pure water. Shock conditions rapidly ensue if vomiting and diarrhoea further complicate the clinical situation.

In the paraplegic child catabolism is more pronounced during the first hours and days after injury than in the adult. In fact, metabolic acidosis is a frequent finding at this stage. The average daily requirements of proteins and calories per kg of body weight which are needed to prevent catabolism are about twice as high in young children than in adults (Tables V, VI and VII). However, since paralytic ileus rarely lasts more than 4 days and normal oral feeding can be resumed at that point, we usually administer only standard glucose infusions and compensate for loss of electrolytes. Preparations containing lipids and amino acids are administered only exceptionally to young patients who are exposed to additional stress such as surgery, hyperthermia, etc. We all know from our experience with adult patients that parenteral feeding with hypertonic glucose and lipids through an indwelling venous catheter carries a high risk of thrombo-phlebitis. The same

TABLE V
Average daily requirements of proteins and calories
(Food and Nutrition Board, U.S.A.)

	Age (years)	Weight (kg)	Calories (kcal)	Proteins (g)
Infant	0-1/6	4	kg × 120	kg × 2.2
	1/6-1/2	7	kg × 110	kg × 2.0
	1/2-1	9	kg × 100	kg × 1.8
Child	1-2	12	1100	25
	2-3	14	1250	25
	3-4	16	1400	30
	4-6	19	1600	30
	6-8	23	2000	35
	8-10	28	2200	40
	10-12	35	2400	45
	12-14	43	2600	50

TABLE VI
Protein requirements per kg body weight

Infant	0-3 months	2.3
	3-6 months	1.8
	6-9 months	1.5
	9-12 months	1.2
Child	1-3 years	0.88
	4-6 years	0.81
	7-9 years	0.77
	10-12 years	0.72
	13-15 years	0.70

TABLE VII
Calorie requirements per kg body weight

3-10 kg	70 cal
10-15 kg	55 cal
15-25 kg	45 cal
25-35 kg	40 cal
35-60 kg	35 cal
Above 60 kg	30 cal

applies to children. If lipids are administered, blood-smears must be checked frequently for the presence of lipid vacuoles which may give rise to fat embolism (Kundert, 1975).

Anticoagulation

Venous thrombo-embolism in infancy and childhood is exceptional (Kaufmann, 1958). Emery (1962) published a report on 25 cases of pulmonary embolism discovered among 2000 necropsies at the Sheffield Children's Hospital. Jones (1975) described 36 well-documented cases of venous thrombo-phlebitis in children and adolescents treated in Scottish hospitals. Renal vein thrombosis ranks highest in frequency, followed by thrombus formation in nasopharyngeal veins, cerebral sinuses and rarely in the lower limbs. Sepsis and trauma are particular risk factors. In Emery's series 15 among the 25 cases with pulmonary embolism also showed signs of severe infection of the upper respiratory tract. On the other hand, it should be borne in mind that pulmonary embolism may be misdiagnosed as broncho-pneumonia. If antibiotherapy remains ineffective and particularly if the child carries an i.v.-catheter, the diagnosis of thrombo-embolism requires further investigations.

At the Stoke Mandeville meeting in 1974 we presented a paper on thrombo-embolic complications in paraplegics and pointed out that the true incidence of deep-vein thrombosis in the lower limbs cannot be estimated on clinical grounds only. In fact, considerably higher values are reported by several authors since the introduction of the ^{125}I -fibrinogen test. To our knowledge no similar studies have as yet been carried out in children. It is quite possible, however, that leg scanning would reveal a significantly higher incidence of thrombotic involvement

in this age-group as well. At the National Spinal Injuries Centre in Geneva children above age 10 are anticoagulated with low-dose heparin according to Kakkar's method (150 i.u. per kg of body weight at 12-hourly intervals; initial injection 12 hours after spinal injury). This age limit has been chosen in view of the fact that the literature mentions two cases only of iliofemoral thrombosis occurring in children below the age of 10.

Psychological Aspects

Upon hospitalisation of an acutely injured paraplegic child, both the medical team and nursing staff may be fully absorbed in establishing exact diagnosis and deciding on appropriate therapy. Too little thought is given to the child's anxieties and fears which are generated by abrupt separation from home and family, by feelings of isolation and despair developing in a closed-off ward for intensive-care and by the hostile-looking equipment required for monitoring and respiratory assistance. It is of utmost importance to create a state of confidentiality (Jackson, 1973) between the hospital-team and the child. Unless this is achieved from the very beginning, future rehabilitation (Sterling, 1961) may turn out to be an endless struggle and progress poorly. The approach of all team-members must be based on an attitude of consistency. This is possible only if there is rapid and permanent exchange of information regarding the patient between all members of the staff.

SUMMARY

Traumatic spinal cord lesions in children are infrequent (2 to 5 per cent of all cases admitted to specialised paraplegic centres depending on whether the upper age limit is set at 10 or 15 years). Traffic accidents are responsible for at least 50 per cent of the lesions; playground accidents and various sports add another 35 per cent. A large proportion of the accidents have been found to be related to the child's normal desire for adventure and exploration. The segment most frequently involved in our own series of 18 cases was the cervical and upper thoracic spine. Histopathological studies have shown that splitting of the cartilaginous end-plate in the growth zone of the vertebrae is a common finding. Radiological signs of spinal trauma are less evident than in adults; they may be totally missing. Precise neurological assessment must rely on repeated examination and close clinical observation, especially in the comatous child with a head injury. Spinal cord involvement must be suspected and the child treated as a paraplegic until definite proof of a normal neurological status is available. Due to a highly labile water electrolyte balance in the early post-traumatic stage and considerable fluctuations in plasma volume and temperature regulation, permanent monitoring of the cardiovascular function, body temperature and diuresis is mandatory. In children below the age of 10, deep vein thrombosis and embolism are exceptional (sepsis creates a high-risk situation requiring anticoagulation). In the initial treatment of spinal injury only conservative measures should be considered; there are no indications for laminectomy, nor for spinal fusion. In the tetraplegic child below the age of 6, skull-traction should be avoided and immobilisation of the cervical segment achieved by bilateral padded head-rests.

RÉSUMÉ

Chez l'enfant, les lésions médullaires traumatiques sont relativement rares (2 à 5 per cent des cas admis aux divers centres de paraplégiques selon que l'on fixe une limite d'âge

à 10 ou 15 ans révolus). La moitié des lésions, au moins, est provoquée par des accidents de la route. Les jeux et activités sportives sont impliqués dans 35 per cent des cas. Une proportion importante d'accidents est en relation directe avec l'esprit aventurier et explorateur que l'enfant manifeste à cet âge. Dans notre série de 18 cas, les segments les plus fréquemment atteints furent le rachis cervical et thoracique supérieur. L'étude histopathologique révèle la présence de fissurations étendues au niveau du cartilage de croissance des vertèbres atteintes. Les signes radiologiques du traumatisme rachidien sont nettement moins évidents que chez l'adulte; ils peuvent manquer totalement. Le bilan neurologique exige initialement des examens répétés et une étroite surveillance clinique, notamment chez l'enfant comateux ayant subi un traumatisme crânio-cérébral. L'enfant sera toujours traité comme s'il était paraplégique, ceci jusqu'à preuve du contraire. Vu l'instabilité de l'équilibre hydro-électrolytique au cours du stade aigu, ainsi que les fluctuations de la volémie et de la thermorégulation, un monitoring permanent des fonctions cardio-vasculaires, de la température corporelle et de la diurèse s'avère indispensable. Chez l'enfant en-dessous de 10 ans, les complications thrombo-emboliques sont tout-à-fait exceptionnelles. (En cas de septicémie, le risque de thrombose profonde est cependant plus marqué et l'enfant devrait être anticoagulé systématiquement). Le traitement initial des fractures vertébrales reste essentiellement conservateur; il n'y a pratiquement jamais lieu de procéder à une laminectomie, ni à une spondylodèse. Chez l'enfant tétraplégique, âgé de moins de 6 ans, la traction crânienne sur étrier de Crutchfield est à proscrire. L'utilisation de supports bitemporaux, convenablement rembourrés, permet dans tous les cas une immobilisation satisfaisante.

ZUSAMMENFASSUNG

Traumatische Querschnittsläsionen im Kindesalter sind relativ selten (2 bis 5 per cent der Patienten, die in Paraplegikerzentren behandelt werden, je nachdem die obere Altersgrenze bei 10 oder 15 Jahren angesetzt wird). Mindestens 50 per cent aller Rückenmarksläsionen sind auf Verkehrsunfälle zurückzuführen. Spiel und Sport sind für weitere 35 prozent verantwortlich. Zahlreiche Unfälle entstehen im Zusammenhang mit einem, in diesem Alter besonders ausgeprägten Bedürfnis nach "waghalsigen" Leistungen und Entdeckungen. Die zervikale und obere thorakale Wirbelsäule waren bei unseren 18 Patienten die am häufigsten betroffenen Segmente. Histo-pathologisch erkennt man Knorpelrisse im Bereiche der Epiphysen. Die roentgenologischen Zeichen eines Wirbeltraumas sind beim Kind schwerer ersichtlich als beim Erwachsenen; oft fehlen sie vollkommen. Der endgültige neurologische Befund beruht auf mehrmaligen Untersuchungen und einer eingehenden klinischen Beobachtung. Dies gilt vor allem für bewussthlose Kinder mit Schädeltrauma. Die Möglichkeit einer Rückenmarksläsion muss in Betracht gezogen und das Kind dementsprechend behandelt werden, bis diese Diagnose mit Sicherheit ausgeschlossen werden kann. Beim Kind ist im akuten post-traumatischen Verlauf der Wasser- und Elektrolythaushalt oft stark gestört; das Plasmavolumen und der Temperaturausgleich weisen starke Schwankungen auf. Deshalb ist ein Monitoring der kardiovaskulären Funktionen, sowie der Körpertemperatur und der Diurese unumgänglich. Bei Kindern unter 10 Jahren sind tiefe Venenthrombosen und Lungenembolien äusserst selten. (Im Verlaufe einer Sepsis ist die Thromboseneigung jedoch deutlich verstärkt; die betroffenen Patienten sollten deshalb systematisch antikoaguliert werden.) Bei der Frühversorgung der geschädigten Wirbelsäule stehen die konservativen Behandlungsmethoden im Vordergrund; es bestehen praktisch keine Indikationen für Laminektomien oder Spondylodosen. Beim tetraplegischen Kind unter 6 Jahren sollte von einer Crutchfield-Extension am Schädel abgesehen werden; gut gepolsterte beidseitige Kopfstützen gewährleisten in der Regel eine genügende Immobilisation.

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