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INTRODUCTION

Past and Present

This book is based on publications, as well as on materials from lectures and seminars for surgical registrars or trainees and from presentations for colleagues at conferences.

In contrast to a spinal cord or central nervous injury, a severed peripheral nerve can be repaired with functional return. Normality, however, cannot be expected subsequent to the repair of a nerve injury in the adult man. In most cases, brachial or lumbosacral plexus lesions are a combination of peripheral and central nervous system injuries. Therefore, they are the most devastating of the nerve lesions and also the most difficult to repair. Restoration of limb function and control of pain after such injuries are formidable and frustrating tasks. Prognosis for spontaneous recovery is often bleak, as there are several conditions under which recuperation is difficult.

Such injuries, located in the most proximal part of the peripheral nervous system (often within the spinal canal and close to the neuron cell body), can give rise to significant neuronal death. If regeneration takes place, the new neurites have to elongate for a long distance. They have to find their appropriate targets and form functional contacts without being sidetracked in the complex intrafascicular communications along the peripheral nerves. However, the most serious problem encountered in present cases of plexus injuries is when one or several spinal nerve roots have ruptured or have been avulsed (torn) from their attachment to the spinal cord (Bonney 1954; Narakas 1993). The root avulsion injury is a spinal cord (or central nervous) lesion, and therefore considered not amenable to treatment (Seddon 1975). It seems appropriate to consider those patients who have sustained plexus avulsion from the spinal cord as suffering from a longitudinal spinal cord injury.

Spinal nerve root or preganglionic injuries are a type of central nervous lesion, although the roots are, for the greater part, of peripheral nervous type. This kind of injury is considered impossible to repair with a functional outcome, as the regrowth of new nerve fibres has to occur to some extent within the spinal cord. Contemporary treatment is therefore palliative, using nerve transfers or neurotisations. Nearby nerves such as the accessory nerve, intercostal nerves, nerves from the cervical plexus, and even the phrenic or spinal nerves from the contralateral uninjured brachial plexus are used. In this approach, the interrupted connection between the spinal cord and the periphery is, to some extent, compensated for by alien nerves. But this is only palliative therapy; ultimately, the injured spinal cord segments will be permanently disconnected from the periphery, leading to secondary changes such as neuronal atrophy and death as well as giving rise to severe, excruciating pain.

The first description of root avulsion in brachial plexus injury was offered by Flaubert (1827) in a study of autopsy cases. The first exploration of a brachial plexus injury with root avulsions by means of laminectomy was performed by Frazier and Skillern (1911). Their case report still remains up to date, as it gives a clear description of the severe pain experienced by the patient after such a lesion and also advocates early intervention.

The first description of intraspinal root repair is of clinical cases of lower motoneuron lesions caused by tumours of the medullary conus in children with myelomeningocele (Carlsson and Sundin 1967). In some of the operated cases, there was functional restitution of bladder contraction by anastomosis of neighbouring sacral ventral roots. Thoughts on palliative nerve transfers from the upper part of the lumbar plexus were given later by Sundin (1972). Recently, descriptions of cauda equina repair after lumbosacral plexus lesion were published (Lang *et al.* 2004).

Direct reconstruction of the connections between the spinal cord and the nerves, after spinal nerve root injury, by implanting or reattaching avulsed dorsal roots to the spinal cord, was first reported by Bonney and Jamieson (1979) in a case of brachial plexus lesion (Birch *et al.* 1998). The first human case of spinal cord reimplantation of avulsed ventral roots where functional recovery could be demonstrated was reported from the Karolinska Hospital in Stockholm (Carlstedt *et al.* 1995). Since then, intraspinal repair of brachial plexus injuries has been reported by other centres as well (Fournier *et al.* 2001; Bertelli and Ghizoni 2003). Recently, the procedure of intraspinal repair of lumbosacral plexus injuries (Lang *et al.* 2004) was successfully repeated in another centre (Tung *et al.* 2005).

Repair of the injured nerve plexus has always been subject to controversy. As early as the Roman times, the physician Galen was met with disbelief when he diagnosed a brachial plexus injury affecting hand function that he successfully treated in a nonsurgical manner (Robotti *et al.* 1995). Later, though initial great achievements had been made by brave surgeons at the beginning of the 20th century, surgical treatment came into disrepute and was abandoned for a long time. Early amputation of the arm used to be recommended. A more aggressive approach emerged with the development of microsurgery and the (overly optimistic) belief in its benefits. A new interest in these injuries arose, and has now led to the establishment of a paradigm for repair of the brachial plexus. The outcome of surgery is so encouraging today that it is no longer a question of what can be done, but of what should be done. Controversies, however, endure.

Thanks to the new molecular biology tools allowing us to explain the reactions of the nervous system to injury and subsequent regeneration, it has become obvious that an emergency operation is optimal for the repair of a nerve injury like a plexus lesion. However, this viewpoint is not adopted by all nerve surgeons. Another issue of debate is the approach to the most proximal of the plexus injuries, i.e. the root injuries or avulsions from the spinal cord. These preganglionic injuries have been considered impossible to repair (Seddon 1975), thus motivating the development of several palliative procedures (see Chapter 5). There is therefore a certain lack of interest in, and even some negligence towards, intraspinal injury to the extent that it is difficult to diagnose with certainty. The absence of surgical interest and exploration of such injuries has not fostered the knowledge in injury patterns, mechanisms, and surgical techniques.

After a rupture, the efferent or motor root would react as a peripheral nerve and, therefore, could give rise to functional recovery if repaired. Repair of severed ventral roots results in recovery of muscle function (Thulin and Carlsson 1969) and/or autonomic function (Kilvington 1907; Freeman 1949). In long series of animal experiments, the original idea (Carlstedt *et al.* 1986) of surgically treating the more central and frequently occurring avulsion of spinal nerve roots, i.e. the longitudinal spinal cord injury, was pursued for many years in the laboratory. The successful outcome of this intervention has been verified in several other laboratories (see review by Carlstedt 1997). This is the first successful instance of a spinal cord lesion where surgical treatment has led to useful functional return. Reimplantation of avulsed roots for the treatment of longitudinal spinal cord injury in plexus lesions has reached application in humans. The experimental background, the injury and its assessment, as well as descriptions of surgical techniques and outcome are here presented and discussed.

This book is also about ideas developed during early studies of the normal anatomy of the interface between the growth-promoting peripheral nervous system (PNS) and growth-inhibitory central nervous system (CNS) in the transitional region (TR) of the dorsal root, performed at the Karolinska Institute in Stockholm (laboratory of C-H Berthold) (Carlstedt 1977) and at McGill University in Montreal (laboratory of A. Aguayo), where the concept of spinal cord regeneration into peripheral nerve conduits was established (David and Aguayo 1981). The ideas were tested first experimentally, in collaboration with Staffan Cullheim, Mårten Risling, and Rolf Hallin; and were later translated to human clinical practice, in collaboration with Georg Noren at Neurosurgery, Karolinska Hospital, as the first step in treating a spinal cord injury, the longitudinal spinal cord lesion. Finally, some thoughts are given on future treatment of this particular lesion and related spinal cord injuries.

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