FROM THE ARCHIVES

Traumatic intradural avulsion of the nerve roots of the brachial plexus, by Patrick Taylor (from the Division of Neurological Surgery, Department of Surgery, University of California at Los Angeles and the Wadsworth Veterans Administration Hospital Los Angeles). Brain 1962: 85; 579–602.

Writing 130 years after the first description of traumatic avulsion of the spinal roots that give rise to the brachial plexus, and sometime after this complication of injury was first demonstrated by myelography, Patrick Taylor supplements an account of three cases observed personally with a review of the literature. The early work, much of it derived from obstetric practice, has established the now classic accounts of Erb–Duchenne [Wilhelm Erb (1840–1921) and Guillaume-Benjamin Duchenne de Boulogne (1806–1875)] palsy of the upper plexus, torn at the C5/C6 junction (Erb’s point), and Mme Augusta Déjerine-Klumpke’s (1859–1927) account of total plexus lesions that might recover to leave the ‘Erb syndrome’ from which she has concluded, based in part on experimental canine studies but later through autopsy evidence, that the presence of Horner’s syndrome indicates involvement of the T1 root. But, although the literature contains around 90 cases confirmed at autopsy or surgical exploration, and three of 10 cases including the three from his own practice: seven have undergone myelography and surgical exploration, and three others have had axon reflex studies but no other interventions. The triple response axon flare provides no information into relative abeyance.

Dr Taylor considers that the apparent rarity of root avulsion, as opposed to direct injury of the plexus, has been under-reported; the investigation of these cases by the axon flare test introduced by George Bonney from the Institute of Orthopaedics in London (UK) in 1959, and the findings in more recent surgical series suggest that >50% of patients with weakness of the upper arm following trauma have avulsed spinal roots and not direct injury to the brachial plexus. And his concept is that various processes and disease mechanisms occur both proximal and distal to the plexus and in its upper and lower structures, and with differential damage to motor, sensory and autonomic fibres which, taken together, determine the clinical picture and prognosis of these injuries. ‘Modifying factors [such] as shoulder dislocation, direct pressure, and compression between the first rib and clavicle…may exist peripherally [when] avulsion involves the same fibres at root level…tension in the nerve roots is necessary to produce avulsion…simple traction…if forceful enough can be transmitted all the way to the spinal cord’.

Previous experimental work has used human cadavers to mimic the common obstetric context showing that forceful separation of the head and shoulders selectively tears the C5 root with frequent involvement also of C6 and C7; but there is less agreement on whether the disruption occurs precisely at the junction of the nerve root and spinal cord or a short distance distally. Self-evidently, in other situations, posture of the arm determines the site of injury. Accidents occurring with the arm hyper-abducted, displaced backwards or in a position of torsion—as when the limb is caught in machinery—are especially likely to avulse the T1 and C8 roots. However, this type of injury may not spare C5 and C6, such damage occurring typically when the head and neck are violently separated. C7 root is especially vulnerable to lateral traction on the plexus due to its shorter and more horizontal course and, since it has no other input, this makes the middle trunk of the plexus selectively vulnerable to traumatic injury. Furthermore, and noting the increased prevalence of non-obstetric circumstances resulting in plexus injury in modern society, C7 is involved more often than any other single root because it tends to be involved both in upper and lower plexus injuries, especially when these are severe. The site of avulsion is usually just proximal to the sympathetic ganglion or at the junction of the rootlets emerging from the cord, and more often involves the anterior than posterior roots. Nor is the cord itself spared, with much evidence from autopsy series for meningeal adhesions, acute cord swelling, long tract degeneration and loss of anterior horn cells.

Because prognosis depends on the presence or not of nerve fibre continuity, more likely with distal than proximal injuries, much is to be learned in this respect by ascertaining the site of injury. Based on the work of Sir Thomas Lewis (1881–1945), the cutaneous axon flare response to intradermal histamine, that depends on continuity of the peripheral axon with its cell body in the dorsal root ganglion, has been used to distinguish pre- and post-ganglionic, or proximal and distal lesions, respectively, and—in the former context—to map the distribution of affected nerve roots. But the triple response axon flare provides no information on anterior nerve root integrity; it cannot evaluate complex proximal and distal injuries; and it is not fully informative until about 3 weeks after injury.

Against this background, Patrick Taylor has studied the details of 10 cases including the three from his own practice: seven have undergone myelography and surgical exploration, and three others have had axon reflex studies but no other interventions.
A.J.D. (aged 23 years) was flung from a car during an accident and found with his arm pinned beneath the vehicle; both myelography and axon flare studies indicate a proximal lesion and surgery confirms avulsion of the C6 root and some C5 rootlets (Fig. 1); but despite restricted damage, his arm is completely paralysed, atonic, areflexic and anaesthetic below the mid-brachium, remaining flail with neuropathic pain (partially relieved by saline injection of the stellate ganglion) throughout follow-up. J.E.L. (aged 18 years) sustained complete paralysis of the arm with subsequent wasting, areflexia, sensory loss and a Horner’s syndrome in a road traffic accident; myelography indicates traction from C5 to T1 but an axon flare is induced only in the C8 and T1 dermatomes; and despite the result of these investigations, surgical exploration confirms complete avulsion of the C6–T1 roots (Fig. 2) from which no recovery has occurred. S.S. (aged 18 years) was thrown from a motorcycle and landed on her face with traction on the shoulder; she was found with a flaccid, paralysed, areflexic and anaesthetic arm; myelography suggests avulsion of C8 and T1 (Fig. 3) and axon flares are obtained in the C7, C8 and T1 dermatomes; no recovery occurs but the causalgic pain that she developed has responded partially to surgical removal of the stellate ganglion.

The obvious finding on myelography is a diverticulum at the level of the spinal root and extending along its course, or partial elongation of the root pouch with bleb formation or extradural collections of myodil indicating leakage from the dural sleeve. Loss of normal filling at the exit of each nerve root, demonstrated some time after injury, indicates avulsion and meningeal scarring equivalent to the acute phase diverticulum (Figs 1 and 3); more subtle is the appearance of traumatic intraspinal arachnoid cysts and meningocoele (Fig. 2) that may compress the spinal cord; and loss of the opacity that normally signifies the intact nerve root in its intrathecal course. The maximum site of nerve injury does usually correspond to the most obvious location of radiographic change although the clinical deficits are invariably more extensive.
than would otherwise be suggested; and clinical recovery is unlikely even in the presence of some apparent nerve fibre continuity as judged by a shadow visible on the radiographs. But it is obvious from the few cases—seven in total including A.J.D. and J.E.L.—that have been extensively investigated and operated upon that there is a poor correlation between immediate clinical deficits, myelography, the axon flare response, surgical findings and functional outcome.

It is for this reason that surgical exploration and nerve root suture are recommended either by laminectomy or the supraclavicular approach, whereas plexus exploration is not advised since this is rarely the site of injury and, when this has occurred, the trauma usually extends over several centimetres and is irreparable. But mere inspection in order to confirm the poor prognosis is not an indication for surgery; and most observers have found the dividend from surgery, in terms of informing on prognosis or improving functional outcome rather disappointing. Intradural exploration—more informative but also more invasive than the supraclavicular approach—is advocated only in the context of persistent pain or the prior demonstration of intraspinal cysts and other surgical lesions.

Are there lessons to be learned from the analysis of cases that do show some improvement? Not unexpectedly, these tend to be upper rather than lower lesions and to have fewer roots involved. Of those with complete paralysis at onset and limited root avulsion, ~40% may show some improvement over ensuing months. Specifically, there is a 50% chance of function being regained when one or two roots are avulsed, 33% with three and no prospect for recovery from more extensive lesions. The period of follow-up is too short to allow comparison of recovery resulting from regeneration in distal versus proximal muscles since the former are bound to take longer. Importantly, recovery may depend on the presence of additional peripheral damage, over and above root avulsion, and this may explain apparent improvements in function where upper root avulsion occurs in association with compression at the thoracic outlet of lower roots that are still in continuity. The presence of Horner’s syndrome, indicating damage at or around the T1 root carries the relatively poor prognosis of the lower lesion generally, although such cases may regain function in their upper roots, and is more reliable in predicting a poor outcome than myelographic evidence for avulsion of T1. Although Horner’s syndrome is rarely seen in association with burning causalgic pain, which is relatively common, both are most likely to occur in lower lesions and each is found to have an equally poor prognosis—even when pain occurs in the presence of partially retained sensation indicating that some dorsal rootlets have survived the injury. Persistent pain, causalgic or of other types, may be an indication for surgical sympathectomy, stellate ganglionectomy, posterior rhizotomy or spinothalamic tractotomy—although with generally disappointing immediate and longer term results that are not obviously better than with conservative management involving chemical sympathectomy and best medical care. Only in the exceptional instances of spinal cord herniation into a traumatic diverticulum or the formation of local adhesions and arachnoid cysts is surgery likely to help the pain. Rather, management should focus on rehabilitation with early orthopaedic measures; a flail limb, properly braced and pain-free with motion augmented by ‘artificial muscle’ devices is much preferable to amputation, as previously advocated.

Given the gloomy outcome and low dividend from surgery, Patrick Taylor’s recommendation of combined myelography, axon flare assessment and surgical exploration may seem difficult to endorse although he recognizes the anecdotal nature of his experience and the limitation of relatively short follow-up in other reported cases. Naturally, he is most interested in the possibility for recovery from early loss of function attributable to peripheral compression of the lower roots at the thoracic outlet: ‘in cases with avulsion from the cord of the upper root fibres, relatively good and early recovery may occur in the distal musculature of the limb…showing the often mentioned and seemingly paradoxical phenomenon of recovery…it is from this group – those with traction of upper roots and reversible compressive lesions of the lower roots – that cases with maximum recovery potential will come’. It is the prospect of a substantial gain in function from a small degree of neurological improvement, perhaps only affecting one movement such as opposition of the thumb and forefinger that inspires Patrick Taylor’s efforts at better understanding of the pathophysiology and management of brachial plexus injury. And is that same motivation to restore a partially useful limb following avulsion of the nerve roots by strategically placed but nonetheless limited tissue repair that forms the basis for cell-based work from the group of Geoffrey Raisman reported in the present issue (page 1268).

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