Penetrating missile injuries of the brachial plexus

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We studied a consecutive series of 58 patients with penetrating missile injuries of the brachial plexus to establish the indications for exploration and review the results of operation. At a mean of 17 weeks after the initial injury, 51 patients were operated on for known or suspected vascular injury (16), severe persistent pain (35) or complete loss of function in the distribution of one or more elements of the brachial plexus (51).

Repair of the nerve and vascular lesions abolished, or significantly relieved, severe pain in 33 patients (94%). Of the 36 patients who underwent nerve graft of one or more elements of the plexus, good or useful results were obtained in 26 (72%). Poor results were observed after repairs of the medial cord and ulnar nerve, and in patients with associated injury of the spinal cord. Neurolysis of lesions in continuity produced good or useful results in 21 of 23 patients (91%).

We consider that a vigorous approach is justified in the treatment of penetrating missile injury of the brachial plexus. Primary intervention is mandatory when there is evidence of a vascular lesion. Worthwhile results can be achieved with early secondary intervention in patients with debilitating pain, failure to progress and progression of the lesion while under observation. There is cause for optimism in nerve repair, particularly of the roots C5, C6 and C7 and of the lateral and posterior cords, but the prognosis for complete lesions of the plexus associated with damage to the cervical spinal cord is particularly poor.

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Penetrating missile injuries (PMI) of the brachial plexus are a challenging group of peripheral nerve lesions. The potentially lethal nature of such wounds produced by damage to contiguous vital structures, and the spectrum of ballistic injury to the plexus elements themselves, have caused uncertainty about the best methods of management. In 1954, Brooks¹ in a MRC Special Report on plexus injuries in war, concluded that operative repair was scarcely worthwhile. Others emphasised the partial neurological deficit associated with these wounds and the expectation that many lesions would recover spontaneously. Useful recovery was thought to be unlikely after repair of such proximal injury.²⁻⁵

In the last 25 years there have been considerable advances in the management of these injuries. Improved treatment of complex penetrating wounds, the application of intraoperative methods to evaluate the nerve lesion and improved techniques of nerve repair justify a more vigorous approach.⁶⁻⁹

We present the experience of the management of PMI of the brachial plexus in the Peripheral Nerve Injury Unit at the Royal National Orthopaedic Hospital, Stanmore. We have attempted to define the present indications for surgical exploration, and to review the results of operation.

Patients and Methods

Between 1975 and 1997, we assessed 58 patients with PMI of the brachial plexus (Table I). Many were referred from outside the UK; 32 injuries were caused by bullets, 15 by shotgun blast at close range, and 11 by shell, mortar or grenade fragments. There were 54 men and four women with a mean age of 28 years (5 to 76).

There was a high incidence of associated injuries of adjacent structures which had been treated by operation before referral. Major vascular lesions (24%) and chest injuries (38%) predominated. Three patients underwent emergency neurovascular repair. One required repair of an oesophageal laceration and another of a wound to the pharynx. Five patients required stabilisation of humeral or clavicular fractures. Injury to the spinal cord occurred in three patients and two others, with complete plexus lesions, had intradural injury and a Brown-Séquard syndrome.

Indications for subsequent exploration. A total of 51

Table I. Details of the 58 patients with penetrating missile injuries of the brachial plexus

Case	Age (yr)	Gender	Wound site*	Initial treatment†	Delay to exposure	Neurological injury‡§	Pain§	Second intervention†	Wound score¶	Nerve function	Pain relief
1	24	F	Supra		4 days	C5,C6 LIC		ENL LIC	1ST	Good	
2	20	M	Supra		6 mths	C7 rupture	NS	NG	1V	Useful	Good
3	25	M	Supra		6 wks	C7 rupture	Causalgia	NG	2ST	Useful	Good
4	27	M	Supra			C5, C6, C7 LIC		-	2ST	Good	
5	44	M	Supra			SSN LIC	NS	-	2ST	Good	Good
6	21	M	Supra	Thoracotomy	6 wks	C7 LIC	NS	ENL LIC, Symp	2V	Good	Good
7	33	M	Supra		2 mths	C5-T1 LIC	NS	ENL LIC, Repair SAA	2V	Good	Good
8	21	M	Supra	Repair pharyngeal wall		C5 LIC		-	2V	Good	
9	35	M	Supra			All trunks LIC	Causalgia	-	2F	Useful	Good
10	24	M	Supra		9 mths	C5, C6, LIC, C7 rupture	Causalgia	ENL LIC, NG	3F	Good	Good
11	5	M	Trans	Repair clavicle	4 days	SSN rupture Trunks/Division LIC	NS	NG ENL LIC	1F	Good	Good
12	25	M	Trans	Repair SA	Same day	PC LIC		ENL LIC	2V	Good	
13	21	M	Trans	Repair SA	Same day	C5, SSN rupture		NG	2VF	Useful	
14	30	M	Trans		10 wks	MC, LC, LIC	NS	ENL LIC, ORIF clavicle, humerus	2VF	Useful	Good
15	28	M	Infra		8 mths	CN LIC		ENL LIC	1ST	Good	
16	22	M	Infra		5 days	MN rupture		NG	1ST	Unknown	
17	58	M	Infra		3 mths	UN rupture	PTN	NG	1ST	Poor	Poor
18	29	M	Infra		6 wks	MN LIC	NS	ENL LIC	1ST	Useful	Good
19	30	M	Infra	Repair SA	6 mths	MCN rupture	NS	Removal of vascular graft	1V		Good
20	17	F	Infra	Repair SA	2 mths	UN rupture	Causalgia	NG, repair AAA	1V	useful	Good
21	25	M	Infra	Repair SA	7 mths	PC rupture	NS	NG	1V	Unknown	Good
22	25	M	Infra		4 mths	MC, LC, PC LIC		ENL LIC	2ST	Useful	
23	22	M	Infra		5 days	MN partial rupture		NG	2S	Useful	
24	29	M	Infra	Chest drain	14 mths	MC, LC, LIC		ENL LIC	2V	Unknown	
25	20	M	Infra	Chest drain	8 wks	MCN rupture MN partial rupture	PTN	NG	2V	Useful	Good
26	37	M	Infra	Repair AA	3 mths	MCN rupture		NG, Revision AA repair	2V	Good	
27	37	M	Infra		8 wks	MN rupture MC, PC, LIC	Causalgia	NG, Repair AAVF ENL, LIC	2V	Useful	Good
28	34	M	Infra	Repair AA	3 mths	MC, LC, PC LIC	NS	ENL, LIC, Repair AAA	2V	Useful	Good
29	34	M	Infra	Chest drain	10 days	MC, LC, PC LIC; SpCI	NS	ENL, LIC, Repair AAA	2V	Useful	Good
30	28	M	Infra	Ex Fix humerus	4 mths	MC rupture	NS	NG	2F	Poor	Good
31	49	M	Infra	ORIF humerus	8 wks	RN rupture	Causalgia	NG	2F	Useful	Good
32	19	M	Infra	Ex Fix humerus	10 days	MN, RN, MCN rupture		NG, Repair AAA	2VF	Useful	
33	34	M	Supra	Chest drain	3 yrs	C5, C6 rupture		NG	2V	Useful	
34	37	M	Supra	Chest drain	3 mths	C5 rupture		NG	2V	Poor	
35	22	M	Supra	Repair SA; chest drain	10 days	C5-C8 rupture; B-S	C6, C7 avulsion	NG	2V	Poor	Good
36	26	M	Supra	Repair SA; Chest drain	Same day	C5, C6, C7, C8, T1 LIC	NS	ENL LIC	2V	Useful	
37	30	M	Supra	Chest drain		All trunks LIC		-	2V	Useful	
38	37	M	Supra	Thoracotomy	6 mths	UT rupture	NS	NG, ORIF clavicle	2VF	Useful	Good
39	24	F	Supra		2 mths	C5-T1 rupture; B-S	Central	NG C5-T1	3V	Poor	Good
40	34	M	Trans	Chest drain	6 wks	LC rupture	NS	NG, ORIF clavicle, Repair SAVF	2VF	Useful	Good
41	19	M	Trans	Repair SV. Chest drain	9 wks	PC, LC rupture		NG, ORIF clavicle	2VF	Useful	
42	24	M	Trans		6 wks	UT rupture	Causalgia	NG, Repair SAA, SGB	2VF	Useful	Good
43	50	M	Trans	ORIF clavicle; Chest drain	48 hrs	C5-T1 LIC		ENL LIC, Repair AAA	2VF	Useful	
44	30	M	Infra	Repair AA	6 mths	MN rupture	NS	NG, Revision AA Repair	2VF	Useful	Good
45	43	M	Infra	Repair AA; Chest drain	9 mths	MN rupture	Causalgia	NG, Symp.	2V	Useful	Good
46	25	M	Infra	Chest drain	3 mths	UN rupture LC, PC LIC	PGN	NG ENL LIC	2V	Poor	Poor
47	29	M	Infra	Chest drain	4 wks	SSN LIC PC rupture	NS	ENL LIC NG	3V	Good	Good
48	21	M	Supra	Chest drain	2 mths	C5 rupture	Causalgia	NG, Repair SAVF	1V	Useful	Good
49	23	M	Supra	Repair oesophageal tear		UT LIC		-	1V	Good	
50	19	M	Supra		5 mths	UT, MT, rupture LT LIC	NS	NG ENL LIC	1F	Useful	Good
51	17	F	Supra	Chest drain	3 mths	C5, C6, C7 rupture, SpC	Central	NG, Repair SAA	2V	Poor	Good
52	42	M	Infra		6 mths	MN		ENL LIC, Repair AAA	1V	Useful	
53	27	M	Infra		12 mths	MCN, MN, UN rupture	NS	NG	1V	Useful	Good
54	76	M	Infra	Repair AA	6 wks	MN partial rupture UN rupture	PTN	NG	1V	Useful	Good
55	23	M	Infra	Repair SV; chest drain	14 mths	UT LIC		-	2V	Good	
56	22	M	Infra	Thoracotomy	2 mths	PC rupture; SpCI		NG	2V	Poor	
57	25	M	Infra			UN partial rupture		NG, Repair AAA		Useful	
58	31	M	Infra		6 mths	MN rupture	Causalgia	NG	1ST	Good	Good

* Supra, supraclavicular; Trans, transclavicular; Infra, infraclavicular

† ExFix, external fixation; AA, axillary artery; AAA, axillary artery aneurysm; AAVF, axillary arteriovenous fistula; SA, subclavian artery; SV, subclavian vein; SAVF, subclavian arteriovenous fistula; ORIF, open reduction and internal fixation; SGB, stellate ganglion block; Symp, sympathectomy; NG, nerve graft; ENL, external neurolysis; LIC, lesion in continuity

‡ UT, upper trunk; MT, middle trunk; LT, lower trunk; MC, medial cord; LC, lateral cord; PC, posterior cord; SSN, suprascapular nerve; MCN, musculocutaneous nerve; MN, median nerve; UN, ulnar nerve; CN, circumflex nerve; RN, radial nerve; SpCI, spinal cord injury; B-S, Brown-Séquard lesion

§ PTN, post-traumatic neuralgia; NS, neurostenalgia

¶ 1, low-energy transfer; 2, high-energy transfer; 3, Massive wound; ST, soft tissue; F, comminuted fracture; V, pleura and/or major vessel; VF, pleura and/or major vessel and fracture

Table II. Measurement of recovery after nerve repair or after nerve injury according to the MRC

Motor recovery	
M0	No contraction
M1	Return of perceptible contraction in the proximal muscles
M2	Return of perceptible contraction in both proximal and distal muscles
M3	Return of perceptible contraction in both proximal and distal muscles of such degree that all important muscles are sufficiently powerful to act against resistance
M4	Return of function as in stage 3 with the addition that all synergic and independent movements are possible
M5	Complete recovery
Sensory recovery	
S0	Absence of sensibility in the autonomous area
S1	Recovery of deep cutaneous pain sensibility within the autonomous area of the nerve
S2	Return of some degree of superficial cutaneous pain and tactile sensibility within the autonomous area with disappearance of any previous over-reaction
S3+	Return of sensibility as in stage 3 with the addition that there is some recovery of two-point discrimination within the autonomous area
S4	Complete recovery

Table III. Grading of results according to the MRC scale

Motor recovery		Sensory recovery	
M4 or better	Good	S4 (normal) or S3+	Good
M3	Useful	S3	Useful
M2	Poor	S2	Poor
M1 & 0	Poor	S1 & 0	Poor

Table IV. Results of repair of 56 nerve elements (36 patients)

Function	Roots/trunks		Cords/nerves	
	Number of nerve elements	Number of patients	Number of nerve elements	Number of patients
Good	2	2	1	1
Useful	12	8	20	15
Poor	15	4	4	4
Unknown	0		2	2
Total	29	14	27	22

patients had surgery at a mean of 17 weeks (3 days to 3 years) after the initial wounding. The indications were, in order of priority, known or suspected vascular injury (16), severe and intractable pain (33), and persistent deep loss of function in a major nerve trunk or trunks (51).

No operations were performed in seven patients showing neurological recovery. These included one with causalgia which appeared to undergo spontaneous remission after several months, and one with incomplete injury of the suprascapular nerve with severe non-causalgic pain, which gradually improved.

Surgical approach. This was determined by the need to secure adequate exposure and control of the vascular axis. The most valuable technique was that described by Fiolle and Delmas¹⁰ who exposed the subclavian and axillary artery from the posterior margin of the scalenus anterior down to the brachial artery. In three patients with an arterial

injury (1 emergency), involving the first part of the subclavian and/or vertebral artery, we used the transclavicular approach.¹¹ In those patients in whom nerve injury was confined to the supraclavicular or infraclavicular portions of the brachial plexus, the appropriate transverse supraclavicular incision or deltopectoral approach with reflection of pectoralis major and minor, was used.

The vascular lesion. False aneurysms or arteriovenous fistulae were repaired in 13 patients. In two, the initial vascular repair was revised. Direct suture of the artery was possible in one patient. Reversed saphenous vein grafts were used in all the others. In one referred case, in which the primary repair was undertaken with a vascular prosthesis, thrombosis and infection with massive fibrosis were seen. In the one case of arteriovenous fistula between the subclavian artery and vein, the lesion was successfully treated by embolisation. There was rapid resolution of pain,

Fig. 1

Case 6. One bullet is embedded in the transverse process of the sixth cervical vertebra and another lies posterior to the second rib. The vertebral artery was patent.

with considerable spontaneous recovery of the C5 and C6 neurological deficit.

The state of pain. We recognised four distinct patterns of severe pain in 35 patients (60%).

Causalgia. This is the most severe of the neuropathic pain states and is usually provoked by partial transection of the lower roots of the brachial plexus, the lower trunk and the medial cord or derivative nerves. It was observed in ten patients (17%) and is characterised by intense burning pain, extending beyond the area of the injured nerve by severe allodynia, which renders physical examination impossible, and by hyperpathia which was described by Nathan¹² as a state "in which all cutaneous stimuli cause the same sensation, a penetrating fiery pain, which spreads from the point stimulated". Causalgia is also characterised by obvious disturbance of sympathetic function, with excess sweating, vasomotor disturbance and trophic changes in the skin, and by an increase of pain in response to emotional or other physical stimuli. Almost alone among pain states, distraction or activity worsens rather than relieves causalgic pain. Properly carried out, sympathetic nerve block can relieve the pain for some hours, although this does not prove that the pain is sympathetically maintained.

Neurostenalgia. This is pain caused by persistent compression, distortion or ischaemia of a nerve and was observed in 19 patients (33%). In most, the nerve trunk was intact and the lesion was neurapraxia, or, at worst, axonotmesis. In neurostenalgia the nerve is, in some way, irritated, tethered, compressed or ischaemic. Treatment of the cause relieves pain.¹³ The rapid relief of neurostenalgia after liberating nerve trunks from an entrapment in scar tissue or callus, or after removal of a missile fragment, is characteristic.

Post-traumatic neuralgia. This pain occurs after nerve injury, usually a partial transection. It is not sympathetic in origin and does not respond to sympathetic block or sym-

patholytic agents. It usually responds to local anaesthetic block of a nerve trunk proximal to the lesion, and was observed in four patients.

Central pain. Pain, from injury to the roots of the brachial plexus central to the dorsal root ganglion in their intradural course, or from injury to the cord itself, was noted in two patients.

The nerve lesion. We encountered 103 damaged nerve elements in the 51 patients who had exploration of the wound. Some nerves were found to be wholly transected, others partially so. Others showed the effects of displacement, lying in a tortuous path resembling the 'barley-sugar' (or Jacobean table leg) appearance of a traction lesion. The diagnosis of transected nerves did not present a problem, but the lesion in morphological continuity certainly did. In the latter, distinction between degenerative lesions of favourable prognosis (axonotmesis) and degenerative lesions of unfavourable prognosis (neurotmesis) rested on the demonstration of intact bundles traversing the lesion, the detection of distal muscular contractions from stimulation of the nerve trunk proximal to it and the presence of compound nerve action potentials (CNAP) traversing injury. Prolonged conduction block was seen in cases in which nerve trunks were displaced or compressed by an expanding haematoma or false aneurysm. The diagnosis was established by demonstrating persisting conduction in the distal trunk.

Operative treatment. Conventional nerve grafting with sural nerve was the mainstay for the repair of ruptured nerves. For partial transection, a partial graft was carried out; the medial cutaneous nerve of the forearm, the superficial radial nerve or the lateral cutaneous nerve of the forearm, was taken from the same limb if the parent nerve was damaged.

External neurolysis was undertaken in patients in whom an injured nerve was in continuity, but constricted or distorted in scar tissue, giving rise to persistent pain, persistent deep paralysis and failure to progress. A fine catheter was placed adjacent to the plexus in most patients presenting with severe pain, allowing infiltration of local anaesthetic for up to five days after operation.

Bony injury. Four patients had open reduction and internal fixation of clavicular fractures.

Wound score. The Red Cross Wound classification¹⁴ was used to score, retrospectively, certain features of each wound including the size of the entry and exit wound, and whether or not there was a significant wound cavity, fracture, or injury to major vessels or visceral injury. The wounds were graded according to the amount of tissue damage: grade 1, low-energy transfer (LET); grade 2, high-energy transfer (HET); and grade 3, massive energy transfer (MET). They were also typed according to the structures involved, soft tissue, vital structure or fracture. The nominal category of the wound was derived from a combination of grade and type to give an indication of the complexity and severity.

Table V. Results of decompression of 47 lesions in continuity (23 patients)

Function	Roots/trunks		Cords/nerves	
	Number of lesions	Number of patients	Number of lesions	Number of patients
Good	13	7	5	4
Useful	11	3	15	7
Poor	0	0	0	0
Unknown	0	0	3	2
Total	24	10	23	13

Assessment of recovery. Our system is based on that developed by Seddon,¹⁵ which was derived from the MRC system (Tables II and III). The results for each nerve, or element of the brachial plexus, were graded good, useful or poor.¹⁶

Results

In each case of shotgun blast there was a complex HET or MET wound. In these 15 patients, there was severe and diffuse neurological injury; two sustained intradural injury and a Brown-Séquard lesion. Bullets (32 patients) predominantly caused HET wounds but, in comparison to shotgun blast, there were fewer disruptions of the plexus (53%) and most were single nerve injuries. Shrapnel fragments (11 patients) usually caused small LET wounds. Rupture or avulsion of elements of the plexus was observed in eight patients with fragment wounds, and vital structures were damaged in nine; two of these had injury to the spinal cord. Of the 51 patients operated upon, 46 were followed for at least two years.

Nerve repair. One or more elements of the plexus was repaired in 36 patients (Table IV). There were three good (8%), 23 useful (64%), and eight poor results (22%). Two patients were lost to follow-up.

Repair of spinal nerves or of the upper, middle and lower trunks produced good or useful results in ten of 14 patients (71%). In three out of four poor results at this level (3 shotgun blast and 1 fragment wound), there was an associated injury to the spinal cord.

Repair of the divisions, cords or terminal branches of the plexus produced good or useful results in 16 patients (73%). These included six grafts of the lateral cord and grafts of the lateral cord to musculocutaneous nerve, eight repairs of the median nerve, one of the posterior cord, and one of the radial nerve. Repairs of the medial cord or ulnar nerve were less successful; only three of six repairs were rated as useful or better. A poor result was obtained in a fragment wound after grafting of a lesion of the posterior cord in association with an injury to the spinal cord.

Neurolysis. A good or useful result was obtained in 21 of 23 patients (91%); two cases were lost to follow-up (Table V).

Vascular repair. Of the 15 vascular repairs, normal circulation to the involved limb was restored in 13. In 13 patients, decompression and repair of a subclavian or axil-

lary aneurysm or fistula, and repair or neurolysis of the plexus significantly improved neurological function.

The relief of pain. Satisfactory relief of pain was achieved in 33 of 35 patients. In one with causalgia, there was spontaneous remission, as originally described by Barnes.¹⁷ Three patients responded to sympathectomy or stellate ganglion block as well as surgery to the nerve lesion. Pain was abolished or significantly relieved in ten patients by dealing with the associated vascular lesion. In 18 patients, surgery to the nerve lesion alone relieved pain, but it persisted in two after grafting of the ulnar nerve. Gradual improvement was noted in one patient with an incomplete injury of the suprascapular nerve with neurostenalgia.

Complications. One patient with an HET bullet wound, who sustained a grossly contaminated, comminuted fracture of the proximal humerus which was treated by an external fixation frame, developed osteomyelitis. We removed the pins, excised the dead bone, and administered appropriate antibiotics; subsequent internal fixation and bone grafting resulted in sound union.

Illustrative case reports

Case 6. A 21-year-old man sustained multiple LET gunshot wounds. Emergency surgery included a right hemicolectomy, right thoracotomy and enucleation of an eye. A right supraclavicular wound was not explored. He discharged himself from hospital, but presented six weeks later with severe pain and profound loss of function in his right arm and hand. There was no major neurological deficit. A bullet was lodged in the transverse process of the sixth cervical vertebra (Fig. 1). The pain was improved for about 12 hours by blockade of the stellate ganglion. Digital subtraction angiography showed no evidence of vascular injury. At operation, a bullet was found to be embedded in the scalenus anterior muscle, adjacent to the cervical nerve. There was no evidence of direct injury to the spinal nerves, or to the trunks of the plexus, but considerable fibrosis surrounded the middle and lower trunks and the subclavian artery. The bullet adjacent to the VIIth cervical nerve was removed and a cervical sympathectomy carried out. There was a dramatic relief of pain after operation, and at follow-up at two years there was good function.

The bullet adjacent to the VIIth cervical nerve caused diffuse, severe pain in the arm and functional disability. At

Fig. 2a

Fig. 2b

Fig. 2c

Fig. 2d

Case 27. Broad-based arteriovenous fistula between the axillary artery and vein demonstrated by digital subtraction angiography.

the time, the pain was considered to be causalgia, and sympathectomy was undertaken because of the good response to the sympathetic block. In retrospect, we consider that the pain was probably neurostenalgia; its dramatic relief with recovery of function should probably be attributed to removal of the bullet adjacent to the VIIIth cervical nerve.

Case 27. A 37-year-old man sustained a LET bullet injury with an entry wound in the right upper chest and an exit wound in the posterior axillary fold. He presented two months after injury with diffuse functional loss in the arm, causalgia, palsy of the median, musculocutaneous and radial nerves, and cardiac failure. The radial pulse was absent. There was a bruit in the axilla and a continuous roaring murmur. Digital subtraction angiography confirmed a broad-based arteriovenous fistula between the axillary artery and vein.¹⁰ At operation, using the approach of Fiolle and Delmas,¹⁰ the fistula was excised and the axillary artery and vein repaired. A 3 cm long lesion of the lateral cord/median nerve was repaired (Fig. 2). Stimulation of the posterior cord above the lesion showed a poor and abnormal action potential, but a definite response in triceps. Two years later, palmaris longus was transferred to abductor pollicis brevis in order to improve abduction of the thumb. At four years after the injury, he remained free from pain, with good overall function. The function of the musculocutaneous and radial nerves was normal and function of the ulnar nerve was good. A useful result was achieved in the

median nerve with protective sensation and no over-reaction, but two-point discrimination did not recover.

A lasting relief of causalgia was observed within days of the repair of the vascular lesion and a worthwhile functional result was achieved.

Case 39. A 24-year-old woman sustained a MET supraclavicular wound from a shotgun blast to her left brachial plexus with rupture of all five spinal nerves and a Brown-Séquard syndrome. Within weeks of her injury, she gave a clear description of post-traumatic neuralgia. At operation, two months after wounding, all five spinal nerve roots were grafted. Her pain remained intense for six months, but had settled after 14 months. Two years after injury, the power of finger flexion was MRC grade 3, the sternal head of pectoralis major MRC grade 4 and deltoid, latissimus dorsi and triceps were MRC grade 2 to 3. Tinel's signs were observed for the median and ulnar nerves in the middle of the forearm, and for the radial nerve at the elbow. The injury to the spinal cord had improved considerably, but there was still some clinical evidence of Brown-Séquard syndrome at four years after injury. Further recovery was largely confined to C8 and T1 (sternal head of pectoralis major, triceps and flexor digitorum superficialis, MRC grade 3; brachioradialis and wrist flexion, MRC grade 2; biceps and wrist and digital extensors, MRC grade 0). Transfer of the third and fourth intercostal nerves to innervate serratus anterior achieved power in that muscle of MRC grade 5, and there was no longer a requirement for a

Fig. 3

Case 29. Lateral radiograph of cervical spine showing scatter of shotgun pellets.

flail arm splint. Protective sensation, comprising warm perception, delayed pressure sense and some pin-prick sensation, was present below the elbow.

This was an unexpected and encouraging result after a MET wound. Since there were no pellets within the spinal canal, the Brown-Séquard syndrome was thought to reflect an injury to the brachial plexus. Interruption of the vessels accompanying the lower roots of the plexus may have provoked a partial and perhaps transient episode, affecting the ipsilateral part of the cord (Fig. 3). We consider that repair of the plexus was at least partially responsible for the relief of her pain.

Discussion

The potential for permanent neurological deficit, as well as the immediate threat to life and limb, has challenged those dealing with missile injuries of the brachial plexus. These injuries are infrequent in civilian practice. In recent military conflicts they have made up 2.6% to 14% of all peripheral nerve injuries treated.^{9,18,19} Until recently, there has been disagreement about the indications for operation on the plexus.

Earlier reports were based largely on experience gained during and after World War II. Missile injuries of the plexus were generally considered to have a poor, almost hopeless prognosis and a non-operative approach of waiting for spontaneous recovery was advocated.¹⁻⁴ Seddon²⁰ classed nerve injuries as neurapraxia (conduction block), axonotmesis and neurotmesis. He later emphasised²¹ that a nerve trunk, apparently in continuity, might have sustained such a level of internal damage that the lesion was, in fact, a neurotmesis not an axonotmesis. We prefer a more simple

classification of nerve injury, of 'degenerative' and 'non-degenerative'. In the first the axons undergo Wallerian degeneration, and, in the second, the lesion is a conduction block.²² Puckett et al²³ illustrated the degree of stretch and contusion of a nerve caused by a high-velocity missile and how a near miss could be as destructive as a direct hit. Davis, Martin and Perrett²⁴ reporting late exploration of 24 military gunshot wounds, observed the strangulating effect of dense scar tissue on elements of the plexus. They suggested that prompt nerve repair, excision of neuromata and neurolysis of immature scars may improve functional recovery.

In recent years, it has been appreciated that many missile injuries to the brachial plexus do not recover spontaneously with time, but cause persistent pain and severe functional disability.^{9,25-27} Kline⁸ reported a series of 141 missile wounds of the brachial plexus treated over 18 years. Of the 90 patients operated on 75 were followed for two years or more. The indication for surgery on the nerves was a deficit in the distribution of one or more elements of the plexus, with failure to improve within two to four months of injury. Other reasons included pain and the formation of a false aneurysm. Lesions in continuity were common. Intraoperative recording of compound nerve action potentials (CNAP) traversing the lesion was seen in 48 of 166 such lesions. Neurolysis of damaged elements produced good or useful results in 44 of these (92%). When no CNAP was found to traverse the lesion, it was resected and grafted. Histological examination of the resected specimens confirmed neurotmetic changes in each case. Of 98 lesions, 55 were repaired by grafts, and 18 of 26 wounds in which direct suture repair was undertaken, recovered useful function or better. The best outcome was achieved in lesions of the upper trunk and in the lateral and posterior cords, but recovery occurred with some repairs of C7 to the middle trunk and medial cord to the median nerve. The results in lesions of the lower trunk and the medial cord were mostly poor.

Several authors have noted debilitating pain after missile injury to the plexus. Jebara and Saade¹⁹ reported causalgia in nine patients with incomplete injury to elements of the plexus with associated injury to axillary vessels. Dramatic relief of pain was observed in all nine after cervical sympathectomy. Others have noted relief of pain after reinnervation of the limb. Kline⁸ reported five cases of causalgia; one patient improved after sympathectomy, and four responded to sympathectomy and repair of damaged plexus elements. Neurolysis or resection of the injured element was of value in severe non-causalgic pain, unresponsive to physiotherapy and medication, in about half of the cases. Vrettos et al²⁷ treated five patients (18%) who had significant pain. Of the five, two had complete relief after surgery, two had significant pain relief and in one there was no improvement. The benefit of early decompression of plexus elements compromised by vascular lesions has been reported by others.^{6,7,25,26}

We observed that shotgun and bullet wounds were usually HET or MET injuries with a spectrum of damage ranging from nerve transection to concomitant pulmonary injury, soft-tissue damage and bony destruction; 25 of our patients (43%) had a combined neurovascular injury. Recent large series of missile injuries to the subclavian and axillary vessels, have reported associated injury to the brachial plexus in over 90% of cases in military conflict and 25% to 35% in civilian practice.^{7,25,26,28} A surprising finding was the severity of neural and associated damage which resulted from small, seemingly innocuous wounds from LET fragments. We considered the violence of the injury and the extent of damage to nerves and adjacent soft tissues to be the single most important determinant of outcome, closely followed by the delay between the injury and repair.

Our results suggest that a vigorous approach is justified in the treatment of missile injuries to the brachial plexus. The core of treatment is operative, directed towards the diagnosis and rectification of the neural and vascular injury. Primary intervention is mandatory when there is evidence of a vascular lesion. It should certainly be possible to diagnose the nerve injury and accurate repair of the nerves may be possible in selected LET injuries with minor con-

tamination. Secondary intervention is indicated by pain, in which causalgia and neurostenalgia predominate, when there is failure to progress or deepening of the lesion under observation. We consider that there is cause for optimism after nerve repair, particularly of the roots of C5, C6 and C7 and the lateral and posterior cords, although the prognosis in complete lesions of the plexus associated with damage to the cervical spinal cord is particularly poor. MET, HET and LET injuries produce lesions which are best treated by operation. MET and HET injuries directly damage nerves, as well as other structures. LET injuries can cause nerve damage by compression or distortion, particularly by the late development of an expanding vascular lesion. As always with nerve injury and the leaking axon, the earlier repair is done the better will be the result.

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