J Neurosurg 79:319–330, 1993

Posterior subscapular approach to the brachial plexus

Report of 102 patients

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✓ A 15-year operative experience with 105 posterior subscapular approaches to the brachial plexus in 102 patients is presented. The procedure is indicated in carefully selected cases, especially where the proximal portions of lower spinal nerves are involved. Its main advantage is proximal exposure of the plexus spinal nerves, particularly at an intraforaminal level. The indications in this series were thoracic outlet syndrome (TOS) in 51 carefully selected procedures, brachial plexus tumor involving proximal roots in 22 patients, post-irradiation brachial plexopathy in 14 cases, and proximal traumatic brachial plexus palsy in 18 patients. Thoracic outlet syndrome associated with neurological loss, recurrent TOS after a prior operation, or proximal brachial plexus surgical lesions involving the spinal nerve(s), especially at an intraforaminal level, can be approached advantageously by such a posterior subscapular approach. The technique should also be considered when prior operation, trauma, or irradiation to the neck or anterior chest wall make a posterior exploration of the plexus easier than an anterior one. Anterior exposure of the plexus is the preferable approach for the majority of lesions needing an operation, but the posterior subscapular procedure can be useful in well-selected cases.

KEY WORDS • **brachial plexus** • **posterior subscapular approach** • **spinal nerve root** • **nerve trunk** • **nerve action potential recordings** • **surgical approach**

ACCORDING to Hochberg,[4] the posterior subscapular approach was originally described in the 19th century by Simon and Estlander for use as a thoracoplasty procedure in the treatment of tuberculosis and thoracic empyema in the pre-antibiotic era. In 1962, Clagett[1] described the same approach as a method to resect the first rib for thoracic outlet syndrome (TOS). The procedure became a standard surgical approach for this disease until recently, when the transaxillary and supraclavicular approaches became more popular. The posterior subscapular approach to the brachial plexus was developed when one of the authors (D.G.K.) was approached by a thoracic surgeon who requested help with a patient suffering TOS-like symptoms complicated by neurological impairment. It was decided that a posterior approach might provide exposure for both first-rib resection and for visualization of the proximal brachial plexus. In 1978, 12 examples of brachial plexus lesions explored through the posterior subscapular approach were presented and preliminary indications for the procedure were discussed.[9] Since then, 105 posterior subscapular approaches have been performed in 102 patients and are described here. Included in this paper are the factors considered important in selecting patients for a posterior operation, details of the operative technique, our results, and several illustrative case reports.

Clinical Material and Methods

Patient Population

The charts were reviewed of 102 patients who underwent one or more posterior subscapular approaches to the brachial plexus. Data collected included the age and sex of the patient, the type of preoperative injury and clinical presentation prior to operation at another institution, the preoperative neurological status and results of preoperative electrophysiological studies, details of the operation performed by us with intraoperative findings and electrophysiological studies, and the postoperative neurological status.

Over a 15-year period (1976 to 1991), 105 posterior subscapular approaches to the brachial plexus were performed on 102 patients at the Louisiana State Uni-

TABLE 1
Brachial plexus lesions in this series categorized by injury type

Injury Type	No. of Cases	No. of Operations
spontaneous thoracic outlet syndrome	25	27
traumatic thoracic outlet syndrome	12	12
thoracic outlet syndrome & prior operation	11	12
brachial plexus tumors	22	22
post-irradiation brachial plexitis	14	14
stretch-contusion trauma	14	14
lacerations	2	2
gunshot wounds	2	2
totals	102	105

versity Medical Center, New Orleans. There were 54 females and 48 males. Patient ages ranged from 19 months to 72 years (mean age 38 years).

Categorization of Cases

As can be seen in Table 1, 48 patients presented with TOS, 22 with a brachial plexus tumor, 14 with post-irradiation plexopathy, and 18 with a traumatic plexus injury. In this group of 102 patients, 61 operations had been performed prior to our posterior subscapular approach. Thirty-six of these patients had undergone 40 prior operative procedures on or close to the brachial plexus before referral to us.

Evaluation of Preoperative Function

After a complete history was taken, the patient's loss of motor and sensory function was graded in an attempt to categorize each element of the brachial plexus as having either total or partial loss.[8] Preoperative electromyography (EMG) was carried out in 76% of the 105 cases. Myelography was carried out in selected patients, particularly in those with trauma and in some with tumor. Angiography was used in some of the cases suspected of having TOS and in several of those with traumatic injuries.

Operative Technique

Positioning of the Patient. The patient is initially turned into a lateral decubitus position and then rolled into a prone position, bringing the operative side close to the edge of the operating table. Rolls are placed laterally under the anterolateral chest wall and transversely beneath both shoulders and the manubrium of the chest. The upper extremity on the operative side is partially abducted and flexed forward at the shoulder. The arm is then flexed at the elbow and secured to a padded Mayo stand at a level below that of the operating table (Fig. 1 *upper left*). The elbow, wrist, and hand are wrapped with protective pads. The operating table is then tilted up 15° to 20° or in a reverse Trendelenburg position to allow further abduction of the shoulder and the scapula. The head is turned toward the operative side and placed on a well-padded donut or on several folded sheets, taking care to keep pressure off the orbits and to maintain the airway. The contralateral arm is padded at the elbow and placed to the side.

Surgical Exposure. A slightly curvilinear skin incision is made centered between the thoracic spinous processes and the medial edge of the scapula (Fig. 1 *upper center*). This placement tends to protect the spinal branch of the accessory nerve and the ascending branch of the transverse cervical artery which course close to the medial vertebral border of the scapula.[2] The spinal or inferior portion of the trapezius muscle is divided along the entire length of the skin incision and the edges are marked at intervals with suture for later approximation. Beneath the trapezius muscle lie the levator scapulae muscle superiorly, the rhomboideus minor muscle somewhat intermediate, and the rhomboideus major muscle inferiorly (Fig. 1 *upper right*). All three of these muscles insert on the medial border or the scapula. A large Kelly clamp is used to dissect beneath them midway between the scapula and the spine. By dividing muscle away from the edge of the scapula, the deeper dorsal scapular nerve and ascending branch of the transverse cervical artery are protected.[2] Segments of muscle are clamped and sectioned between two Kelly clamps, beginning inferiorly and proceeding superiorly. If the rhomboid muscles are thick, they are divided into two layers and each of the edges are marked with heavy suture. Paired sutures of heavy Vicryl (polyglactin 910) are placed behind each clamp and tied; the needles are left attached and the ends "fastened" to adjacent drapes so that subsequent approximation of divided muscle is as accurate as possible. As dissection approaches the neck, the thicker portion of the trapezius muscle can be split somewhat in a medial direction and, if necessary, the levator scapulae muscle can be clamped, divided, and marked by sutures as well. Occasionally, some of the serratus posterior muscle is also sectioned.

After division of the rhomboid muscles, the posterior chest wall is exposed. The surgeon then has a relatively avascular plane beneath the scapula and with gloved fingers can create a plane between the shoulder blade and chest wall. One blade of a medium or large self-retaining chest retractor is placed beneath the scapula and the other is inserted into the paraspinous muscle mass. A length of the paraspinal muscle mass can be split down to the posterior chest wall to permit firm placement of the medial blade of the thoracic retractor. The retractor is opened as the limb on the Mayo stand is lowered and/or the operating table is elevated to provide further abduction and external rotation of the scapula.

The ribs are then palpated. Running the fingers superiorly over the second rib permits palpation of the first rib. Sharp dissection of intercostal muscles on the caudal side of the rib and the scalene muscles on the cephalad side as well as use of an Alexander periosteal elevator and Doyen rib dissectors help to clear the rib of soft tissues.[2] The first rib is removed extraperiosteally, from the costotransverse articulation posteriorly to the costoclavicular ligament anteriorly (Fig. 1 *lower*

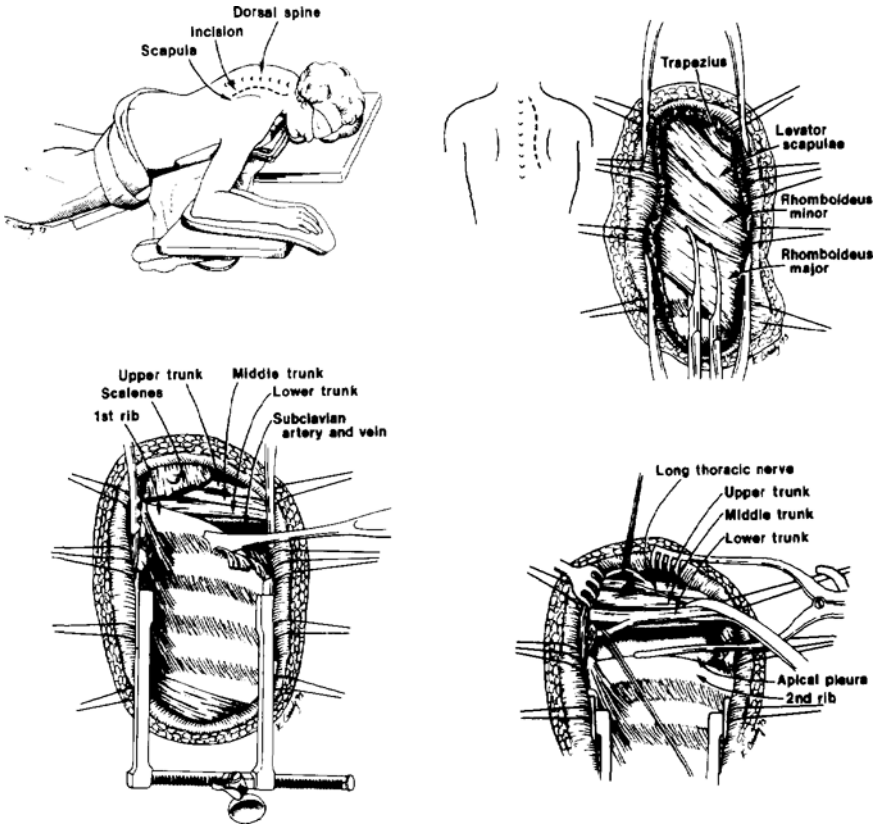

FIG. 1. Operative drawings. *Upper Left:* Positioning of the patient on the operating table for subscapular approach to the plexus. Rolls are placed under the chest and transversely beneath the shoulders. The arm is abducted at the shoulder, flexed at the elbow, padded, and placed on a Mayo stand. The head is turned toward the operative side and placed on a donut. The operating table is placed in a reverse Trendelenburg position 15° to 20° above the horizontal axis. *Upper Center:* Line of the parascapular incision. *Upper Right:* The trapezius muscle has been sectioned and a portion of the rhomboid muscles are about to be sectioned between two long Kelly clamps. Divided muscle edges are marked on both sides by suture for subsequent closure. *Lower Left:* A self-retaining chest retractor is placed beneath the scapula laterally and embedded in the paraspinous muscles medially, then gradually opened as the arm is further abducted by lowering the Mayo stand and/or raising the operating table. The scalene muscles have been detached from the superior surface of the first rib while a periosteal dissector is used to remove intercostal muscles from the inferior rib surface. Early exposure of the subclavian vessels and lower trunk of the plexus is seen. *Lower Right:* After resection of the first rib and scalene muscles, one blade of a Weitlaner or similar retractor is placed against the superior surface of the second rib and the other blade in the superior soft tissues of the neck. Paraspinal muscles are retracted by a large rake so as to expose the spinal nerves or roots. If necessary, either Kerrison rongeurs or a high-speed drill can be used to remove overlying facets to provide exposure of roots close to their dural exits.

left). Leksell rongeurs and/or sometimes a rib cutter are used to resect the rib. Periosteum is resected along with the rib. Subperiosteal resection of the posterior portion of the second rib is sometimes useful in exposing the first rib in very large patients or for large tumors extending into the mediastinum. Bone edges should be carefully manicured and waxed to minimize injury to pleura or surrounding tissues. The posterior and middle scalene muscles are released from their insertions and are resected to their origin from the transverse spinous processes. The roots of spinal nerves and the trunks of the brachial plexus are exposed after removal of these muscles superiorly (Fig. 1 *lower right*). The roots and divisions are further exposed by following the trunks medially as well as laterally. The extraspinal course of the nerve roots is dissected back to the spine. Some elevation and retraction of the paraspinous muscle mass exposes lateral posterior spine overlying the intraforaminal course of the spinal nerves.

A Weitlaner retractor can be placed on the second rib and in the superior soft tissues of the neck to open up the supraclavicular space posterior to the plexus. A malleable chest retractor can be placed over the apical pleura to protect it as the posterior and medial portion of the first rib is removed between the T-1 and C-8 nerve roots. The lower trunk is then isolated from the underlying subclavian artery and exposed circumferentially. Dissection of the plexus can then proceed medially along its roots of origin and laterally along its posterior and anterior divisions. The middle trunk is

FIG. 2. Operative photograph showing proximal exposure of the spinal nerves of the plexus on the left side by a posterior subscapular approach. The patient had a stretch injury involving proximal plexus roots, so facets overlying the spinal nerves were removed by both a drill and use of Kerrison rongeurs. Midline is to the right. The five roots as well as the three trunks of the plexus can be seen. The T-1 spinal nerve is seen at the bottom of the photograph and the C-5 at the top.

isolated next and, if necessary, the upper trunk. The long thoracic nerve will be visible as it originates from the posterior aspect of the C-6 or sometimes C-5 and C-7 nerve roots, and can be protected.

With this exposure, the phrenic nerve will be anterior to both the upper trunk of the brachial plexus and the anterior scalene muscle, which is usually not divided during this procedure. Nerve roots are dissected free in a circumferential fashion; the use of Penrose drains around the various elements including the roots to gently retract them helps in the dissection. If indicated, intraoperative nerve action potential (NAP) recordings can then be obtained. Lateral dissection can extend to divisions, but it is difficult to gain much exposure of the cord level of the plexus with such a posterior approach.

If necessary, the facet joint can be removed using a high-speed drill and/or Kerrison rongeurs to expose the intraforaminal course of the spinal nerve (Fig. 2). In most cases, the nerve can be traced to its dural exit by careful bites with a rongeur, keeping the rongeur footplate on top of the nerve but not compressing it. The vertebral artery lies anterior to the roots so that the roots can be readily unroofed without fear of serious bleeding. More laterally, the subclavian artery is anterior and inferior to the lower trunk of the brachial plexus, while the subclavian vein is anterior to both. Both vessels are identified early in the dissection and can be readily dissected away from the lower trunk and easily protected. If more than two facet joints are removed, the area of bone removal is filled in with methyl methacrylate.

After the brachial plexus procedure, it is important to achieve meticulous closure of the wound by approximation of the divided but previously marked muscles. Thus, anatomical reapproximation of the different muscle planes of the greater and lesser rhomboid muscles as well as most of the spinal portions of the trapezius and levator scapulae muscles is necessary. Good hemostasis must be obtained. A Penrose drain is sometimes, but not always, placed with one end deep to the muscle closure and superior to the apical pleura. The other end of the drain is then brought out posteriorly through a separate stab wound. Any pleural rents must be repaired. The integrity of the pleural repair is tested by filling the wound with saline and having the anesthetist perform a Valsalva test. A chest tube is seldom needed.

Results

Thoracic Outlet Syndrome: General

Fifty-one operations were performed for TOS on 48 patients (27 women and 21 men). The diagnosis of TOS is difficult and requires exclusion of other disorders such as serious cervical spondylosis and disc disease, Pancoast's syndrome, more peripheral entrapments, and on occasion degenerative disease of the spinal cord. In addition, some findings indicate, but are not necessarily by themselves diagnostic of, TOS.[11] These symptoms include supraclavicular tenderness greater than that of the paraspinal and trapezius muscles, a history of "heaviness in the shoulder and arm," and fatigue associated with pain and paresthesias especially when the arm is used in an elevated position. Paresthesias radiating to more distal limbs can also be produced by percussion over the plexus in some patients thought to have TOS. Although dampening of the radial pulse with abduction of the arm and on rotation of the head can be positive in the asymptomatic patient, if it occurs on the side of the symptoms and is present along with other findings favoring TOS, it further suggests the diagnosis. Decrease or loss of function clinically and/or electrically in the C-8 and/or T-1 nerve root distributions favors TOS when other causes for such loss have been excluded. The finding of an osseous abnormality such as a cervical rib or an elongated C-7 transverse process further supports the diagnosis, but TOS is not always present in such cases even though it seems to be the most likely explanation for the patient's symptoms.

Spontaneous Thoracic Outlet Syndrome

Twenty-five patients presented with spontaneous occurrence of symptoms and without neck or shoulder injury or previous operation on the brachial plexus (Table 2). Two patients had symptoms in both arms and were operated on bilaterally. All patients experienced pain, but this was the only symptom in just four patients. Pain was commonly located in the shoulder with radiation down to the upper arm and sometimes to the forearm and hand. Most patients in this series also had mild-to-moderate symptoms related to decreased function of the arm and/or hand.

Fifteen patients presented with mild-to-moderate lower plexus element deficit. Deficit was severe in an additional eight patients. These losses usually consisted of weakness or paralysis of intrinsic hand muscles, including not only the interosseous, lumbricales, and

TABLE 2

*Summary of thoracic outlet syndrome (TOS) cases in this series**

Feature	Spontaneous TOS	Traumatic TOS	TOS & Prior Operation
no. of cases	25	12	11
no. of ops†	27 (2)	12	12 (1)
sex (M/F)	12/13	7/5	2/9
mean age (yrs)	35	40	33.5
prior neural ops			
carpal tunnel release	2	1	0
ulnar transposition	2	2	0
TAR	0	0	11
other	0	0	3‡
clinical presentation			
pain	27	8	12
mild deficit	8	6	3
moderate deficit	7	2	6
severe deficit	8‖	0	0§
EMG with denervation (C-7, C-8, or T-1 distrib)	13 of 24‖	2 of 12	1 of 9
cervical rib	5	0	1
elongated C-7 transverse process	4	1	0
abnormal intraop NAP's	12 of 16	5 of 9	6 of 10
no. of cases followed up	23	11	10
average follow-up period (yrs)	4.6	3.3	3.3
postop status			
good results	19	8	9
unchanged	4	3	1
scapular winging	0	1	1

* TAR = transaxillary rib removal; EMG = electromyography; intraop NAP = intraoperative nerve action potential.

† Numbers in parentheses denote patients with bilateral operations.

‡ Two dissections of supraclavicular plexus, one cervical laminectomy.

§ Three patients with severe loss after prior TAR for TOS had traumatic plexus injuries (see Table 5).

‖ Eight patients with severe deficit and abnormal EMG's had classic Gilliat-Sumner hands.[13]

FIG. 3. Operative photograph in a patient with thoracic outlet syndrome and a cervical rib. Midline is to the right. The plexus is viewed from the patient's head looking toward the scapula. The T-1 nerve root, encircled by a plastic loop, joins the C-8 root to form the lower trunk. A cervical rib *(arrow)* is present below these elements and between them and the C-7 nerve root. Further below are the C-6 and C-5 nerve roots.

hypothenar muscles but sometimes thenar intrinsic muscles such as the abductor pollicis brevis and opponens pollicis muscles. Many of these patients thus had a Gilliat-Sumner hand.[13] Electromyography (EMG) was performed in 24 cases with abnormal results in 13. Thus, EMG confirmed a denervation pattern at the C-8 or T-1 level; in some of these patients there was C-7 loss. Plain x-ray examination revealed a cervical rib abnormality in five cases and an elongated C-7 transverse process in four other patients.

The operation consisted of decompression of the plexus by resection of the first rib and scalene muscle and removal of any compressing fibrous or osseous elements, as well as an external neurolysis of the plexus (Fig. 3). Bands of connective tissue or an edge of a scalene muscle seemed to entrap plexus spinal nerves in some cases, while in others the plexus appeared tight or taut and seemed to relax after neurolysis.[11] Nerve action potential recordings were retrievable in 16 of the 25 patients with spontaneous TOS. In 12 cases, NAP's were of small amplitude and slowed conduction velocity when the C-8 and T-1 nerve roots were stimulated and recordings were obtained from the distal lower trunk. When recorded from upper compared to lower elements, NAP's were greater in amplitude and had more rapid conduction.

Twenty-three postoperative follow-up evaluations are available at a mean postoperative period of 4.6 years. Nineteen patients exhibited a good result with either relief or significant improvement in their preoperative pain. Most of those with mild deficit and three of those with moderate hand intrinsic muscle loss preoperatively had some improvement in function on follow-up evaluation. Surprisingly, three patients with severe loss also regained some function over time. Nine patients also had stabilization of their neurological deficit so that hand intrinsic weakness did not progress over their period of follow-up evaluation. Four patients were either unchanged or worse postoperatively. Two of these patients with operative failures were suspected later of having lower motor neuron disease.

Thoracic Outlet Syndrome After Injury

Twelve patients developed TOS symptoms after an injury to the neck or shoulder, having suffered what is sometimes called "traumatic TOS"[11] (Table 2). Injury had occurred 2 months to 4 years prior to the onset of symptoms. This group of patients was an average of 5 years older (40 years of age) than those with "spontaneous TOS." The pattern of pain did not differ from

TABLE 3

*Summary of 22 brachial plexus tumor cases in this series**

Feature	Schwannomas	Solitary NF	NF-VRD	Malignant NST	Other
no. of cases	5	5	5	3	4†
sex (M/F)	2/3	2/3	1/4	2/1	1/3
mean age (yrs)	49	54	13.5	49	40
prior treatments					
biopsy	3	1	0	3	1
partial removal	0	0	2	0	2
TAR/ant scalenectomy	0	1	0	0	1
cervical laminectomy	0	0	1	0	0
radiation therapy	0	0	0	0	1
clinical presentation					
pain	2	2	0	2	2
no or mild deficit	5	4	4	2	3
moderate/severe deficit	0	1	1	1	1
gross total resection	5	4	2	2	4
postop status					
intact	5	3	4	2	3
deficit	0	2	1	1	1
scapular winging	0	0	1	0	0
scoliosis	0	0	0	0	1

* NF = neurofibroma; VRD = von Recklinghausen's disease; NST = nerve-sheath tumor; TAR = transaxillary 1st-rib resection.

† One case of lymphangioma, one of plasmacytoma, and two ganglioneuromas.

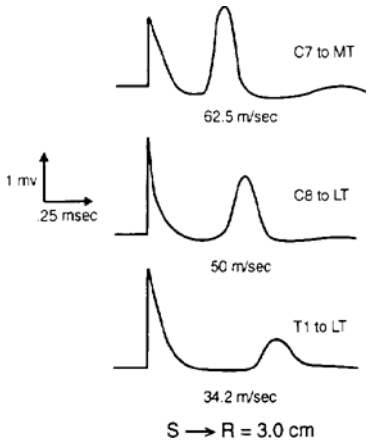

FIG. 4. Nerve action potential recordings made from plexus elements of Case 1, a patient with thoracic outlet syndrome. Conduction and amplitude of the T-1 spinal nerve to the lower trunk (LT) were decreased, while changes in C-8 to the LT were less and recordings from C-7 to the middle trunk (MT) were normal. S → R = stimulation to response electrode distance.

that of the latter group but, somewhat surprisingly, no severe neurological deficit was encountered in the traumatic group. Eight patients did, however, have a mild-to-moderate deficit, usually involving intrinsic muscles and/or C8–T1 distribution sensory changes. Of 12 EMG recordings, only two were abnormal (in the distribution of C-7 to T-1 roots). The usual posterior subscapular approach was performed. The NAP recordings across the lower elements in nine patients gave the following results: NAP's from lower elements (C-8 and T-1 to lower trunk) were of small amplitude and slowed in five patients; NAP's from all elements were of good amplitude and velocity in four patients. Eleven patients were available for follow-up evaluation after a mean postoperative period of 3.3 years. Symptomatology, particularly pain, had improved in eight patients and was unchanged in two. One other patient required placement of a dorsal column stimulator for persistent and very severe pain.

Case 1. This 31-year-old woman police officer presented with neck and shoulder pain, as well as a droopy shoulder. Onset of symptoms occurred shortly after a car accident 2 years before. She did not feel she had been seriously injured in that accident. Neurological examination, EMG, and cervical myelography were normal. Thoracic outlet syndrome was suspected because of the shoulder pain, local tenderness over the supraclavicular plexus, and paresthesias radiating down the arm on percussion of the supraclavicular space.

The patient underwent surgery via a posterior subscapular approach to the plexus. A dense band of connective tissue was found draped posteriorly across and compressing the C-8 and T-1 nerve roots. The roots and trunks were dissected free. The following NAP recording conduction values were obtained: T-1 to the lower trunk 34.2 m/sec; C-8 to the lower trunk 50 m/sec; and C-7 to the middle trunk 62.5 m/sec. Amplitudes of the traces of C-8 and especially T-1 to the lower trunk were small compared to those recorded from the middle trunk after stimulation of C-7 (Fig. 4). When examined 19 months postoperatively, the patient was free of pain and had full muscle strength and normal sensation in the right upper extremity.

Thoracic Outlet Syndrome With Prior Operation

Eleven patients who subsequently had 12 posterior subscapular operations presented to us after 13 prior operations on the brachial plexus, including 11 transaxillary and two supraclavicular plexus dissections (Table 2). The symptomatology included recurrence of pain in all patients. Pain was associated with mild-to-moderate neurological deficit in nine patients; the EMG tracings were normal in eight while one showed partial denervation of the C-8 and T-1 innervated muscles. In one patient a cervical rib was shown on x-ray films. In each of these 11 patients, a posterior operation was performed to further decompress the brachial plexus. Spinal nerves and plexus trunks were treated with neurolysis; residual first ribs and the cervical rib were resected. Scar tissue was usually found involving the lower elements of the plexus. In three cases, residual bands or fascial edges of medial or minimus scalene muscles also appeared to compress the lower plexus elements. Most patients had abnormal NAP studies across the lower elements and more normal conductions and amplitudes on the upper elements. Follow-up evaluations were available for 10 patients (mean follow-up period 3.3 years); nine had improvement in pain, and the one whose pain was unchanged under-

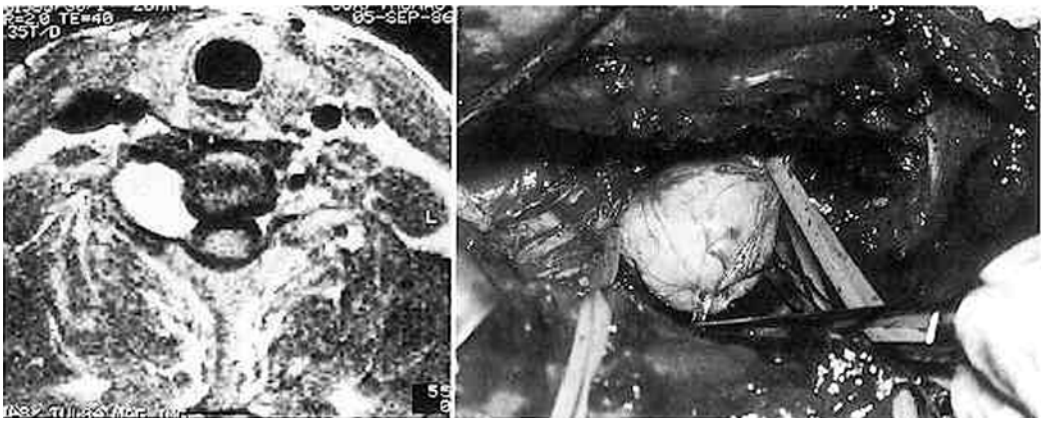

FIG. 5. *Left:* Magnetic resonance image of the cervical spine showing a large right-sided neural sheath tumor of the C-7 spinal nerve. The tumor has an extra- as well as intraforaminal component, both of which could be exposed by a posterior subscapular approach. *Right:* Operative photograph showing dissection of the tumor. On the right one fascicle encircled by a plastic loop enters the proximal pole of the tumor, while on the left a fascicle exits the distal pole of the tumor. No nerve action potential was transmitted by stimulation of the proximal fascicle and recording from the distal one. The fascicles at both tumor poles were thus sectioned to completely remove the tumor.

went repeat neurolysis through an anterior approach with only partial improvement. Most of those patients with a preoperative mild deficit had some improvement in function on follow-up evaluation as did three of those with a moderate deficit. The other patients did not show progression of their deficits on follow-up examination.

Another three patients who had undergone transaxillary first-rib removal for TOS sustained severe injury to the plexus requiring repair. These are considered under traumatic brachial plexus injuries.

Brachial Plexus Tumors: General

Twenty-two patients presented with brachial plexus tumors which were then operated on via a posterior approach (Table 3). The mean age in this group was 40 years. Twelve of the 22 patients had prior biopsy or partial tumor removal. Fourteen tumors involved the C-8 and/or T-1 nerve roots and/or the lower trunk, and most tumors, regardless of level, had an intraforaminal component (Fig. 5).

Schwannomas

There were five schwannomas, one being associated with von Recklinghausen's disease. Only two patients with schwannomas presented with some degree of pain. No patients had either a severe or moderate neurological deficit, whereas one had a mild sensory deficit.

The schwannomas in this series involved the lower elements. One of them mimicked an apical lung tumor and was first approached by a thoracic surgeon who performed a thoracotomy and recognized the nature of the lesion. The tumor was not biopsied or removed, but was subsequently resected with sparing of C-8, T-1, and lower trunk function.[5] Each schwannoma was completely resected by use of microsurgical technique and repetitive NAP recordings, with preservation of the involved element. One other patient underwent total resection of a C7–8 level schwannoma by the posterior subscapular approach, combined with a posterior C1–2 laminectomy for removal of a C-2 neurofibroma.

Neurofibromas

Ten neurofibromas involving the plexus were operated on via a posterior approach. Five cases were associated with von Recklinghausen's disease; these included four females and one male, with a mean age of 23.5 years. Five patients presented with a solitary neurofibroma; these included three females and two males and were significantly older (mean age 54 years) than those with von Recklinghausen's disease. Four of the 10 patients had undergone a prior operation on their tumor. In eight patients the tumors involved lower elements. Two patients presented with pain as the only symptom, seven had a mild-to-moderate neurological deficit, and one presented with complete middle-trunk functional loss after transaxillary first-rib resection and scalenectomy. With the use of magnification with loupes and repetitive NAP recordings, complete resection could be achieved in six cases. Almost complete but subtotal removal was performed in four cases. Two patients with solitary neurofibromas and one associated with von Recklinghausen's disease had less function after surgery than preoperatively. All three patients had undergone prior operations on their tumor. The mean follow-up period for all 10 neurofibroma patients was 3 years.

Malignant Nerve-Sheath Tumors

Two cases of neurogenic sarcomas (malignant schwannomas) and one case of fibrosarcoma were treated by wide local resection through a posterior subscapular approach. The patient with fibrosarcoma underwent both a posterior and a subsequent anterior

approach for further tumor removal and then received irradiation. The patient was followed for 5 years without recurrence but has since been lost to follow-up evaluation. The two patients with malignant schwannoma had extensive but subtotal tumor removal from a subscapular approach. Postoperatively, the pain experienced before surgery was improved in both cases but one patient had some increase in his neurological deficit. Both patients with malignant schwannoma died from widespread metastatic disease, one at 16 months and the other at 4 years postoperatively.

Case 2. This 40-year-old male physician had noticed paresthesias in the right hand for a few months, followed by weakness of the right shoulder, wrist, and hand. Computerized tomography (CT) and magnetic resonance imaging of the neck revealed a large supraclavicular brachial plexus mass with extension into the mediastinum. Needle biopsy suggested a malignant tumor.

Partial dysfunction was noted in the distribution of the C-5 and C-6 innervated muscles. Loss of function was severe in the distribution of the C-7, C-8, and T-1 elements. After excision of the first rib and the posterior and middle scalene muscles, a mass 8 cm in diameter was dissected circumferentially, with maintenance of the capsule. A plane of dissection was found posteriorly, superiorly, and laterally, whereas inferiorly and medially the tumor was more adherent and the capsule had to be entered to remove tumor from superior and medial pleura as well as deeper mediastinal structures. The core of the tumor was relatively soft and moderately vascular. It was necessary to remove some tumor from the C-5, C-6, and C-7 nerve roots and upper and middle trunks as well as from the C-8 and T-1 roots and lower trunk. Tumor was also attached to the subclavian vessels, first rib, apical pleura, and the anteromedial mediastinum. A section of pleura 4 cm in diameter was resected and replaced with fascia lata. Foramina at the C6–7 and C7–T1 levels were entered for tumor removal, but a small amount within the spinal canal could not be excised. On NAP recording, good-sized NAP's were obtained from C-5 and C-6 to the upper trunk, moderate-sized NAP's from C-7 to the middle trunk, but only a trace from C-8 and T-1 to the lower trunk. Permanent histological sections confirmed the diagnosis of a neurogenic sarcoma.

The patient gained good pain relief and, surprisingly, over a 1-year period recovered some C-8 and T-1 spinal nerve function with improved hand intrinsic muscle function. This occurred despite treatment by irradiation and chemotherapy. He survived a little over 4 years postoperatively, then died from disseminated disease.

Miscellaneous Tumors

There were four additional patients with brachial plexus tumors. Two patients had secondary involvement of the brachial plexus by a soft-tissue tumor. One lesion was a lymphangioma involving both the C-8 and T-1 nerve roots. The patient had undergone partial tumor resection by an anterior approach elsewhere and presented to us with severe pain and some sensory deficit. Removal of the residual tumor was achieved via a posterior approach. His pain was improved and neurological status was intact postoperatively. The other patient had a plasmacytoma involving the lower three roots. She had previously undergone resection of the mediastinal part of the tumor as well as irradiation. The recurrent tumor, which involved the brachial plexus, was resected via a posterior subscapular approach. The tumor exhibited some malignant changes, with no demarcation from the lower roots. As a result, a wide local resection of the tumor as well as of the C-7, C-8, and T-1 elements was performed. Postoperatively, the patient was free of pain and, as expected, had no distal function in the distribution of the lower nerve roots. A recurrence of the tumor 2 years postoperatively has been treated by chemotherapy, and she has survived another 3 years without further recurrence. Two additional patients, a 5-year-old girl and a 63-year-old physician, had ganglioneuromas successfully resected from the mediastinum as well as from lower plexus elements.

Post-Irradiation Plexopathy

Fourteen patients previously irradiated for cancer were operated on for painful brachial plexopathy. There were 11 women and three men, with a mean age of 50 years. The primary malignancy was breast cancer in eight cases, Hodgkin's disease in three, pulmonary cancer in two, and thyroid cancer in one (Table 4). The time interval between radiotherapy and onset of disabling symptomatology and, therefore, surgery ranged from 15 months to 18 years (mean 8 years). Pain was the predominant symptom, but four patients also presented with a very severe neurological deficit. Decompression of the irradiated plexus by first-rib resection via the posterior approach was performed, as well as neurolysis and removal of scar tissue. Associated metastatic tumor was found in three cases. Follow-up evaluation was available in 12 patients: pain was improved in eight, but in seven function had deteriorated. One of the patients who did not improve subsequently underwent amputation of a severely painful flail arm.

Among the 14 patients classified as having "post-irradiation brachial plexopathy," tumor metastatic to the plexus was discovered intraoperatively in three cases. The original lesion was breast cancer in two and pulmonary cancer in one. In this subset the interval between radiotherapy and onset of symptoms was 10 years, $3\frac{1}{2}$ years, and 15 months, respectively. Loss of function in these three patients was probably due to the metastasis to the plexus and change due to irradiation. The presence of severe actinic changes, with large amounts of scar tissue, was the predominant operative finding. These three patients are categorized as having "actinic plexitis" in this section.

Case 3. This 39-year-old right-handed woman had a simple mastectomy in 1982 for breast cancer. Postoperatively, she received 23 x-ray treatments and 6 months of chemotherapy. She underwent reconstructive surgery with an attempted placement of a breast prosthesis, but developed skin infection and had to have a skin graft. She had noticed progressive hand and forearm weakness since 1983 and severe arm and hand pain for several years. In early 1986, she underwent a first-rib resection

TABLE 4

*Summary of 14 post-irradiation brachial plexitis cases in this series**

Feature	Primary Malignancy			
	Breast Cancer	Hodgkin's Disease	Lung Cancer	Thyroid Cancer
no. of cases	8	3	2	1
sex (M/F)	0/8	1/2	2/0	0/1
mean age (yrs)	54	40	56.5	40
mean interval RT to plexopathy (yrs)	8.8	9	4.5	3
prior operations				
mastectomy	8	0	0	0
thoracotomy	0	1	2	0
neck dissection	0	0	0	1
biopsy plexus	1	1	0	0
cervical laminectomy	0	0	1	0
CTR	1	0	0	0
TAR	1	0	0	0
clinical presentation				
severe pain	4	2	1	1
mild or moderate pain	4	1	1	0
no or partial deficit	5	2	2	0
moderate/severe deficit	3	1	0	1
brachial plexus lesion				
all roots	3	1	0	1
upper roots	2	1	0	0
lower roots	3	1	2	0
cancer found at op	2	0	1	0
postop status				
pain improved	5	1	1	1
pain unchanged	3	2	1	0
added plexus deficit	4	2	0	1
scapular winging	1	0	0	0

* RT = radiation therapy; CTR = carpal tunnel release; TAR = transaxillary 1st-rib resection.

TABLE 5

Summary of 18 brachial plexus trauma cases in this series

Feature	Injury Mechanism		
	Stretch/ Contusion	Laceration	Gunshot Wound
no. of cases	14	2	2
sex (M/F)	10/4	1/1	2/0
mean age (yrs)	31.5	26.5	22.5
neurological status			
severe pain	2	0	1
partial loss of elements	3	0	0
complete loss of 1 or more elements	11 (5 flail arms)	2	2
associated injury			
major vascular	2	1	2
fractured ribs, cervical spine	1	1	0
pneumothorax & spleen laceration	1	0	0
subdural hematoma	1	0	0
mean interval trauma to op (mos)	15	2	2
type of repair			
neurolysis	5	0	1
direct suture	0	1	0
grafts	9	1	0
neurotization	0	0	1
result			
3 yrs postneurolysis (5 cases)			
no recovery	1	0	0
grade 1–2	0	0	0
grade 3 or better	4	0	1
5 yrs postgrafting (8 cases)			
no recovery	1	0	0
grade 1–2	2	0	0
grade 3 or better	5	1	0
5 yrs postsuture (1 case)			
grade 3 or better	0	1	0
scapular winging	1	0	0
cervical spine instability requiring fusion	1	0	0

through a transaxillary approach, but believed that her hand weakness and pain increased postoperatively.

Upon examination in mid 1986, the hand and forearm were swollen and somewhat stiff. In the supraclavicular area there was a mild fullness and the skin was thickened and had telangiectasia. Tapping on this area elicited a Tinel's sign with electrical shocks radiating down to the fingers. Supra- and infraspinatus muscles were graded 5/5, the deltoid, biceps, and brachioradialis muscles were 4/5, and the triceps had only trace strength at 1/5. There was no wrist flexion or extension, no thumb or finger flexion or extension, and no hand intrinsic muscle function. These findings were consistent with a complete actinic plexopathy in the outflows of the C-7, C-8, and T-1 roots or spinal nerves.

The patient underwent a posterior subscapular approach to the plexus. The residual first rib was removed as well as an elongated C-7 transverse process. The plexus demonstrated an anatomical variation, being postfixed with a contribution from the T-2 nerve root. A large amount of scar tissue was removed from the lower elements. Histological examination of this area revealed not only dense fibrocollagenous tissue but also metastatic carcinoma of breast origin. After neurolysis, NAP recordings gave no electrical response from C-8, T-1, or T-2 to the lower trunk and none from C-7 to the middle trunk. The postoperative course was uneventful. Neurological function remained the same as preoperatively; however, good pain relief was achieved until the patient died from metastatic disease 3 years later, in 1989.

Traumatic Plexus Injuries

Eighteen patients were operated on posteriorly for traumatic brachial plexus palsy (Table 5). There were 13 males and five females in this subset. Patient age ranged from 19 months to 61 years (mean age 28 years). In 14 patients, the injuries were secondary to stretch-contusion trauma. Automobile or motorcycle accidents caused injury in eight cases, iatrogenic stretch-contusion trauma from a transaxillary operation in three cases, football injury in one, snowmobile accident in one, and birth-related stretch injury in one. Two injuries were due to laceration, one from a stab wound and the other from transection by a scalpel during transax-

illary first-rib resection. Two patients sustained a gunshot wound to the plexus.

Preoperatively, 15 patients presented with a complete deficit in the distribution of one or more plexus elements. Five of these patients had a flail arm. An incomplete but severe and persistent deficit was present in the other 10 patients. Patients were operated on because of persistence of complete denervation in the distribution of at least one plexus element and/or severe pain.

At operation, 10 patients were found to have ruptured or transected elements or absence of NAP's across a lesion in continuity. After resection of these lesions, sural grafts were placed. Neurolysis with removal of scar tissue was performed on one or more elements in six patients because of the presence of regenerating axons proven by NAP recordings. The patient with birth injury was explored at 19 months postinjury because of complete C5–6 loss; NAP's were recorded from the upper trunk divisions after stimulation of both C-5 and C-6, so only a neurolysis was performed. Recovery in this distribution began 1 year later, and follow-up evaluation at 11 years of age shows acceptable shoulder and arm function. Neurotization using the descending cervical plexus was performed in one patient with a gunshot wound to the plexus in whom the proximal plexus elements were found impossible to repair. In another patient, an iatrogenic laceration of the C-8 nerve root was treated 2 weeks postinjury by end-to-end anastomosis.

Eight of 10 patients with graft repair had a follow-up period of at least 5 years: one patient underwent amputation of a painful flail arm, one recovered strength to only 1/5, another to 2/5, and five patients recovered to a level of 3/5 or better. Five of six patients treated by neurolysis had a follow-up period of at least 3 years: one patient made a poor recovery, three had a good recovery, and one an excellent recovery. The patient with end-to-end suture of the C-8 root after an iatrogenic laceration recovered to 3/5 strength in that distribution by 5 years postoperatively. One patient (Case 4) with a stab wound involving the dural level of C-5 and C-6 roots which was partially repaired by grafts has made a good recovery to date. No follow-up evaluation is available for the patient who underwent the neurotization procedure, as this was carried out relatively recently.

Case 4. This 18-year-old right-handed woman was stabbed from behind in the left paracervical area with a long knife. She immediately noticed absence of movement of the shoulder girdle and loss of elbow flexion. The entrance wound was sutured at her local hospital. Cervical spine x-ray films and a CT scan showed fracture of the left C-5 and C-6 transverse processes and some of the facet structure. Computerized tomographic myelography showed poor filling of the C-6 nerve root sleeve (Fig. 6).

When examined 3 months postinjury, the patient had total paralysis of the left supraspinatus, infraspinatus, deltoid, biceps, brachioradialis, and supinator muscles. The remaining muscles of the left upper extremity were all functioning but somewhat weak. There was no Horner's sign. Because of the proximal, as well as complete, injury of the C-5 and C-6 nerve roots, it was decided to explore the plexus by a posterior subscapular approach.

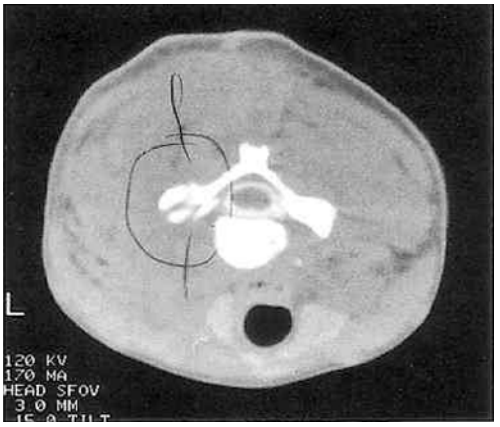

FIG. 6. Computerized tomography scan with metrizamide myelography with cut at C-5 to C-6 level in Case 4, a patient who had been stabbed in the neck. There is a fracture of the left facet and poor nerve-root sleeve filing at this level. Loss was complete in the left C-5 and C-6 to upper trunk distribution. The plexus was approached posteriorly. The C-6 spinal nerve had been shorn off flush with the dura, while the C-5 nerve had enough extradural root to be used for a graft repair.

Roots and trunks were exposed from behind. The elements were scarred but still in continuity, although the upper trunk was reduced to scarred threads of neurofibrous tissue. Extensive scar tissue was removed up to and into the neural foramina. During C4–5 and C5–6 foraminotomies, a lacerated vertebral artery was found occluded by organized clot and scar. The vessel ends were clipped and cauterized. The C-5 and C-6 roots were injured at their emergence from the dural sac. The C-6 nerve root was scarred even medial to its dural exit, whereas some fascicular structure remained in the C-5 root. Four sural nerve grafts, 1.5 in. long, were placed between the C-5 root and the anterior and posterior divisions of the upper trunk.

The patient's postoperative period was uneventful. Examination at 14 months postrepair revealed that the supraspinatus muscle was graded 3/5, the infraspinatus and deltoid muscles 1/5, and the biceps 2/5, but there was no brachioradialis muscle as yet. Subsequent follow-up evaluation at 3 years indicated further improvement in shoulder abduction (deltoid muscle 3/5 to 4/5) and forearm flexion (biceps and brachioradialis muscles 3/5). She could now use this arm to carry school books.

Discussion

The posterior approach to the brachial plexus provided some advantages over the classical anterior approach in an earlier small series of cases.[9] In a larger series of 171 operations on brachial plexus injuries and tumors reported in 1983,[8] an anterior approach was

used for most cases. A few cases of tumors and gunshot wounds involving the lower roots and some irradiation injuries involving multiple roots which were approached by a posterior subscapular route were also reported. The main advantage of the posterior approach, as seen in the earlier and in the present cases, is a relatively easy exposure of the plexus spinal nerves or roots at very proximal levels. In the primate, such an approach provides an excellent exposure of the intraforaminal portion of the spinal nerves.[7] It is possible to spare the important and related vessels and nerves with an anterior plexus dissection, but for exposure of lower elements close to or within their foramina this is more readily done by the posterior approach. Specific comments on each group of patients selected for a posterior operation follow.

Thoracic Outlet Syndrome

Fifty-one operations were performed posteriorly for primary or recurrent TOS. This remains a difficult diagnosis to be certain of, but a large number of patients in this series either presented with neurological deficit and/or had undergone a prior operation on the thoracic outlet. Most also suffered severe pain which was considered not to be related to another diagnosis. Despite these observations, not all of these patients were helped by the posterior operation. Our usual surgical procedure of choice for TOS is an anterior supraclavicular approach, with exploration of the lower elements, relief of any osseous and/or soft-tissue compression, and neurolysis of the plexus. The anterior approach can provide relatively safe access and adequate exposure of even the lower elements in most TOS cases; however, the posterior approach is appropriate in selected cases. This is especially so with recurrent TOS after a prior anterior or transaxillary operation, in cases where injury to lower elements has occurred, and in patients where a significant bone abnormality such as a large cervical rib is present.

The usual neural TOS appears to be at a proximal level and involves lower plexus roots or spinal nerves. Intraoperative NAP recordings indicated conductive abnormalities that began at a spinal nerve to trunk level, especially along lower elements such as the T-1 and C-8 spinal nerves or roots. Results in TOS patients after a posterior approach compare favorably with those approached through an anterior technique. On the other hand, the posterior approach, when used for TOS, is a larger operation than the anterior one and can occasionally result in winging of the scapula.

Brachial Plexus Tumors

In 1987, Lusk, *et al.*,[12] reported on a series of tumors involving the brachial plexus. Among the 56 patients with 57 tumors involving the brachial plexus, 10 were operated on via the posterior approach due to involvement of proximal and/or lower plexus elements.

Among the 22 patients with brachial plexus tumors operated on posteriorly in our series, 13 had undergone partial anterior removal and/or a biopsy before our operation and 14 tumors involved the C-8 and T-1 spinal nerves and/or lower trunk. These considerations made the posterior route more attractive than the anterior approach. The posterior subscapular approach was extremely useful in exposing both the intra- and extraforaminal part of dumbbell-shaped tumors, most of which were neurofibromas.

An earlier report included seven malignant neurogenic plexus tumors and emphasized that management must be individualized.[12] Although the posterior approach is advantageous for malignant tumors involving spinal nerves, wide local resection and postoperative radiotherapy are usually the only choices at this level. In such cases, forequarter amputation will not be effective because of the medial extent of the tumor.

Radiation Plexopathy

All 14 patients with radiation injuries operated on posteriorly had severe pain which was usually the main reason for the operation. Upper roots were involved predominantly in only two cases. The most common pattern was either involvement of all roots or of the lower roots alone. First-rib resection as well as neurolysis with removal of extraneural scar tissue was used in an attempt to decompress the plexus. This may be worthwhile if severe pain is unresponsive to medical treatment and persists; however, seven of the 12 operated patients with follow-up evaluation had decreased function postoperatively. Nonetheless, the posterior subscapular approach avoids the heavily scarred tissues of the anterior neck area associated with the anterior and axillary ports of irradiation.

Traumatic Plexus Injuries

One-fifth of the spinal nerves or roots injured by stretch and inspected via the classic anterior approach are not reparable, even in patients selected for operation, because of damage at an intraforaminal or spinal cord level.[3,10,14] In primates, a posterior subscapular approach combined with a facetectomy exposed, on the average, a 7.2-mm segment of spinal nerve not approachable by an anterior procedure.[7] Results of the present study indicate that a posterior approach can also be used in the human to expose the intraforaminal portion of the spinal nerve or root injured by stretch in selected cases.

In this small series of stretch injuries operated on posteriorly, the facet joint was removed by a Kerrison and/or high-speed drill to expose the intraforaminal course of the spinal nerve. The nerve was then traced to its dural exit and, as a result, could sometimes be repaired at a level not readily accessible by an anterior approach. There are limitations to the procedure as well as potential complications. One child with a severe stretch injury operated on posteriorly, while recovering some function in the upper element distribution, required posterior fusion for a progressive scoliosis. Fortunately, the lateral extent of the stretch injuries selected for posterior operation was accessible, but that is also a limitation if this approach were to be tried on all stretch injuries.

Two lacerating injuries to the plexus were operated on posteriorly. In the patient with the stab wound, nerve roots were transected flush with the dura, and

any direct repair would have been difficult except through a posterior approach. The other patient had iatrogenic division of the C-8 spinal nerve during transaxillary first-rib resection, and an end-to-end repair of this lower element was more readily done from a posterior than an anterior approach.

Two additional patients sustained gunshot or missile injuries to the proximal plexus. Gunshot wounds to the plexus are usually operated on via an anterior approach because they either involve the infraclavicular plexus, or if supraclavicular, upper rather than lower spinal nerves. A review of 90 surgically treated gunshot wounds to the plexus reported in 1989 included 21 injuries at a spinal nerve to trunk level and 69 at a division to cord or cord to nerve level.[6] Only three patients with injury of the lower, proximal elements were considered candidates for the posterior approach. The two additional patients reported in this series had both undergone an acute anterior operation for vascular repair, and had complete loss of function of spinal nerves at a proximal supraclavicular level.

The indications for the posterior subscapular approach at the present time are summarized in Table 6. Some of the potential serious complications are also included in this table. Most brachial plexus lesions requiring surgery can be operated on expeditiously through an anterior approach; however, in well-selected cases, the posterior subscapular approach can be advantageous.

TABLE 6

Indications for posterior subscapular approach to plexus

Thoracic outlet syndrome
1. large cervical rib or other posteriorly located bone abnormality
2. prior operation such as transaxillary or supraclavicular 1st-rib resection where posterior third of rib is present
3. cases associated with injury to & loss involving lower plexus elements with or without prior operation
Brachial plexus tumors
1. lesions with both intraforaminal as well as extraforaminal lateral components
2. tumors involving plexus & extending into mediastinum &/or compressing apical pleura and lung
3. tumors involving lower spinal nerves (especially C-7, C-8, and T-1)
Irradiation plexopathy
1. severe pain in patients with extensive anterior neck & chest wall change due to irradiation
2. relatively early but progressive loss in lower element distribution where anterior supraclavicular ports or superior-anterior chest ports were used
Traumatic plexus injuries
1. knife, glass, or metallic penetrating wounds involving plexus spinal nerves close to the spine
2. gunshot wounds involving plexus spinal nerves close to the spine &/or at an intraforaminal level
3. selected stretch injuries where preoperative studies suggest very proximal involvement but not total avulsion, particularly of spinal nerves responding relatively well to repair such as C-5, C-6, and C-7
Potential complications of the posterior approach
1. scapular winging
2. potential instability of the cervical spine if more than 2 facets are removed, such as for a severe stretch injury at multiple levels
3. pleural tears, pneumo- or hemothorax, phrenic nerve palsy, or new & further damage to the plexus, as can occur with an anterior operation

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Manuscript received October 2, 1992.
Accepted in final form March 15, 1993.

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