THERAPY

Diagnosis and treatment of brachial plexus injuries

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Abstract

In the reconstruction of the nerves in traction injuries of brachial plexus, the main role is the correction of the function of upper extremity. This article is aimed at establishing a diagnosis, indications for intervention and surgical treatment. Operation results are influenced by a degree of injury, type of surgical therapy, patient's age, and by the time delay between the injury and the intervention *(Ref. 6)*.
Key words: brachial plexus, diagnosis and surgical treatment.

Lesions of brachial plexus involve not just a single nerve, but numerous nerve roots, trunks, fascicles and branches that are linked by complex anatomical relationships. These nerves may be affected by several types of injuries occurring not only at specific sites but also at several levels along individual nerves. Severe injuries of brachial plexus are associated with injuries of scalene muscles or fractures of transverse processes on cervical vertebrae.

Traction injuries caused by traffic accidents are the most frequent causes of brachial plexus injuries.

Major force directions resulting in supraclavicular injuries of brachial plexus include:

1) descending injuries of upper trunk,
2) traction of the arm abducted upwards causes injury of the lower trunk,
3) traction in the anteroposterior direction may damage selectively the C7 root. Vigorous tractions may affect all roots.

Infraclavicular injuries are caused by dislocation or traction of the arm in case of fracture.

Hyperabduction of the arm may cause interruption of n. axilaris, n. suprascapularis and n. musculocutaneus at their first point of fixation. This point is quadrilateral, composed of n. axilaris, m. coracobrachialis and n. musculocutaneus. N. suprascapularis may be disrupted in the vicinity of suprascapular incision or it may be torn off by the muscle.

The forms somewhere between supra- and infraclavicular injuries are frequent, with possible injuries on both levels. Surgical examination should therefore include both levels.

Diagnosis of brachial plexus injuries

The diagnosis is based on clinical and neurophysiological examinations and images.

Clinical examination

Clinical picture depends on the degree of the injury of brachial plexus, histological degree of nerve injury, on the period between the injury and examination, as well as on the presence of associated injuries of the affected extremity. Neuropraxis (which is present in majority of brachial plexus injury) may last up to 6 weeks. In the initial period it is therefore difficult to evaluate the possibility of spontaneous recovery.

The examination of deep pressure sensitivity is a useful part of the examination aimed at evaluating the continuity of a nerve that does not show the signs of motor or sensory functions. This examination can be performed by the grip of patient's fingers in the nail area. Induced pain is transmitted by small sensory filaments. This maneuver may reveal the continuity of a nerve even in an evidently insensitive finger that is not respond to burning.

Thumb tip corresponds to the C6 root through n. medianus and lateral fascicle. The tip of the middle finger corresponds to the C7 root through n. medianus and through the branch of C7

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root to lateral fascicle. The last phalanx of the little finger corresponds to the C8 root through n. ulnaris and medial fascicle. These small nerve filaments show high resistance to nerve compression caused by injury and swelling and are functional even when all other filaments are inactivated. Neuropraxis can slow down or even interrupt transmission in these filaments. The absence of sensitivity during the first 6 weeks after the injury therefore cannot be taken as a diagnostic sign of the rupture of a specific nerve. These small filaments may be functional but the examination might be performed too early.

The absence of pain in the anesthetic arm or foot points to root avulsion. Initiation of pain in the insensitive arm is a sign of the deafferentation due to pulling out the root from spine. Pain is rare in postganglional lesions.

Dry skin in the anaesthetic area indicates postganglial injuries while the skin with normal moistness indicates preganglial injury. Sensitivity on the inner side of the arm is usually normal since it is innervated from the Th2 root and from the intercostobrachial anastomoses and not from brachial plexus.

Avulsion of the roots may cause partial spinal lesion. Brown-Sequard syndrome may be present as well. Spinal lesion and hematoma may disseminate the injury and may cause partial paralysis of intercostal nerves. This must be taken into consideration during reconstruction of the plexus. Both arterial bleeding present in penetration injuries and traumatic aneurysm may cause compression.

Functional degree of nerve compression is compared to the loss of motor and sensory functions. Lack of correlation indicates that nerve compression is more likely than nerve rupture. Repeated examinations after hours or days may reflect changes in clinical findings.

Avulsion of C8 and Th1 roots and lesions in the vicinity of spinal canal and corresponding spinal roots interrupt sympathetic preganglial filaments, which causes Horner syndrome (vasodilatation, anhydrosis, miosis, ptosis). Enophtalmus as a symptom in the Horner syndrome is disputable. Miosis is frequently observed as the only symptom with other symptoms only partially developed.

Isolated lesion of the C7 root generally does not result in a complete muscular paralysis since proximal muscles innervated from C7 root are simultaneously innervated also from C6 root and distal muscles innervated from C7 root are innervated also from C8 root. Injury of C7 root affects the sensory function only at minimal degree since is covered by C6 and C8 roots. Muscular paralysis and sensory deficit are evident in case of associated spinal nerve or trunk injuries.

Images

X-ray examination of the C part of spinal column is necessary for the identification of osteal traumas in the plexus area and for exclusion of unstable fractures and dislocations. It may show osteal abnormalities, e.g. neck rib. Fractures of transverse processes point to possible avulsions or ruptures of neural roots. Fractures of clavicula, fractures of humerus or dislocation of arm may be associated with injuries on corresponding level of plexus.

Elevation of one half of diaphragma detected by chest X-ray may indicate diaphragm paralysis due to damaged n. phrenicus. This lesion indicates the injury of upper cervical roots.

Computer tomography (CT) can display fractures of transverse processes which are not evident on X-ray. PMG-CT may reveal small meningoceles. The presence of meningocele does not necessary mean a root avulsion. In children, menigocele may be present on contralateral nerve roots with preserved normal function.

Magnetic resonance (MR) may detect extradural or intradural hematomas, edemas and hemorrhagic permeation to soft tissues. Both CT and MR provide useful pre-operational information. However, their informative value is insufficient for the verification of a preserved continuity of nerve roots.

It is difficult to clinically exclude vascular damage therefore all serious injuries of brachial plexus should be subjected to angiographic examination.

Filaments of the upper and medial trunks run in more deeply situated nerves and end more proximally, so they are less accessible to neurophysiological examination. Therefore most information is derived from neurophysiological examinations of both arm and forearm by means of nerve filaments running in lower trunk and medial fascicle.

Interpretation of examinations can be difficult, especially in cases with multiple lesions involving spinal roots, plexus and its branches.

Although image analysis and neurophysiological examination allow a prediction of surgical findings, they do not influence the indication for intervention. The indication for surgical treatment is based on clinical examination that may reveal a partial or complete lesion of brachial plexus without signs of recovery.

Timing of the surgical treatment

As in majority of surgery, the success in the surgery of peripheral nerves depends predominantly on correct evaluation of arguments for or against the operation. The ability of denervated muscles to recover after re-innervation is limited.

Vascular injuries result in an avulsion of less elastic nerves. Vascular injuries require an early and rapid surgery. Direct bleeding from the wound requires an urgent revision and control of blood vessels with the aim to reconstruct circulation. In the first place it is necessary to relieve compression of the nerve by edema or by necrotic muscles. Delay in the treatment of an injured artery more than 8 hours results in a minimal chance of functional recovery due to an increasing pressure in fascial compartment and following ischemic fibrosis.

If the presence of an experienced surgeon is necessary, surgical treatment in the majority of uncomplicated open injuries of nerves without vascular damage can be postponed for 24 hours. Stab wounds without vascular damage but with present neurological deficit should be treated during 2–3 days.

In cases without symptoms of root avulsion or vascular lesions but with persistent complete paralysis, delay up to 2 months is acceptable. If no signs of recovery are observed during this period, the injury must be revised. However, if the recovery is continuous and all nerve roots show some signs of continuity, surgical revision may be postponed.

In the presence of dissociative palsy (paralysis without sensory deficit), a delay of several weeks is acceptable. In some cases, it is better to wait with incomplete paralysis up three months for further improvement before surgical revision. Another factor to be considered in the timing of operation is a discontinued recovery of specific muscle groups where the residual deficit is still significant although some signs have improved (1).

If the deep sensitivity on the lower trunk is preserved, revision of only upper trunks should be performed. However, if the deep sensitivity on small finger is absent, the exploration of the whole plexus should be performed within 3 months.

Surgical treatment is indicated if absolutely no recovery is observed for closed injuries of brachial plexus and the deep sensitivity to pressure is absent on each finger for a period up to 2 months. In these cases, timing of the operation is discussed, generally with early revision recommended (within 2 weeks by some surgeons) (2, 3).

Early revision has several advantages compared to easier revision, as well as the early identification of nerve injuries and early treatment by neural graft or by other type of reconstruction surgery. Surgical field is without cicatrized tissue, and axons in the distal stump as well as neuromuscular junctions continue their function for several days. Stimulation of distal stump elicits motor response that allows the identification of fascicles with predominant motor function. Delay is accompanied by a progressive intra-neural fibrosis. Favorable conditions for reconstruction can be immediately capitalized since they may later disappear. Patient may be informed about the prognosis and the rehabilitation may start early.

The disadvantages of an early operation are linked to problems in the evaluation of arm function in the early stage. Surgeon has limited knowledge about the degree of injury of individual roots and this lack of knowledge interferes with continual per-operational decision process (3, 4, 5). However, the problems associated with late surgery overweight the disadvantages of the early surgical treatment.

It is not recommended to extend the observation and examination period for more than 4 months if no signs of recovery are observed. Actually, recovery within this period could be expected only in case of neuropraxis. Axonotmesis of roots or trunks may show no signs of recovery during 6 to 8 months. If surgical revision is postponed to this time, reconstruction surgery has inferior outcome. Therefore the decision to intervene on supraclavicular lesions must be done long time before signs of recovery in axonotmesis might be expected.

When treated later, nerves can become stenotic and lack sufficient vascular supply in long segments. If we do not find gross anatomical changes on the nerve during revision, we may rely on relatively rapid recovery. In ischemic damage, indication for a resection of altered neural segments must be considered after evaluating the dynamics of the process during first months after the intervention. This is because recovery of an impaired neural transmission may be observed after decompression and even after apparently serious damage.

Frontal approach

Patient lies on his back with the upper part of chest supported by gauzes, in total anesthesia without muscular relaxation. Supraclavicular part of plexus is made accessible by the incision from the lower third of lateral margin of m. sternocleidomastoideus along the upper edge of clavicula to its lateral third. Vena jugularis is retracted or ligated. Lateral attachment of m. sternocleidomastoideus is abducted medially without the need of interruption. M. omohyoideus is interrupted in the central part and abducted medially and laterally by sutures. This way is made accessible also m. scalenus anterior located right behind vena jugularis interna. Following step is the protection of n. phrenicus.

N. phrenicus is branching from the C5 root. Proximally along n. phrenicus we find the C5 root. During the operation we observe supraclavicular sensory nerves. Along them proximally we observe how they leave the C4 root. After the identification of C4 root and C5 root, the upper level of brachial plexus may be determined. Palpation with the finger usually helps to localize carotic tuber on the C6 transverse process. Following steps are isolation of C5 and C6 roots and of the upper trunk.

First, the suspected roots should be examined proximally. To be able to identify each root of brachial plexus, m. scalenus anterior may be interrupted transversally. The roots should be inspected up to the foramen with the aim to identify the injury. Per-operational stimulation is useful for confirmation of the functions of n. phrenicus, nerve roots, as well as nerve selected for a transfer. Attention should be paid during the stimulation, if the contracting muscles are in the area of an injured nerve. It must be clear that the impulse was not disseminated to neighboring, intact muscles or nerves.

In case of suspected arterial injury, surgical treatment is suggested to acquire proximal and distal control over arteria subclavia, identified at the junction between m. scalenus anterior and first rib. To get proximal and distal control, arterial strips will be placed around a. subclavia before the preparation of an affected area.

Thereafter, clavicula will be isolated. All bone splits or protrusions from healing fracture that could eventually compress plexus are removed.

M. subclavius must be interrupted as laterally as possible. Arteries and veins of medium length are located beneath m. subclavius and its fibers. Subsequently the whole plexus is exposed and treated if necessary.

After the revision of an infraclavicular area, the infraclavicular part of the incision continues to the insertion of m. pectoralis major to the humerus. After the identification of musculopectoral furrow both muscles separated to reveal v. cephalica and the tendon of m. pectoralis minor fixed to procesus coracoideus. After proximal interruption of v. cephalica the tendon of m. pectoralis minor is separated from processus coracoideus and medially abducted. Subsequently, distal fascicles of brachial plexus could be identified. N. musculocutaneus is the first visible nerve since it is lying laterally under the insertion of the tendon of m. pectoralis minor. Lateral fascicle is located medially and somewhat deeper. Posterior fascicle is directly under the lateral fascicle. Medial fascicle is located medially and under the arteria axilaris. Branches between the medial and lateral fascicles should be preserved during the preparation.

One should try to preserve all structures crossing the brachial plexus in order to sufficiently preserve soft tissue covering plexus. These structures are represented by m. omohydoideus and m. subclavius as well as by m. pectoralis minor and major in the supraclavicular region.

If one of abovementioned muscles is contracted, it must be re-fixed after extension, as well as the clavicular origin of m. pectoralis major to the clavicula.

Reconstruction

The majority of brachial plexus injuries is represented by combined lesions including multiple plexus elements with various degree of nerve injury. Various types of neural damage can be present as these injuries form a complex with ruptures at various levels or they include avulsion of nerves from muscles or lesions in continuity, the latter forming the majority of nerve injuries.

Surgical treatment ranges from neurolysis to reconstruction. The treatment starts usually with neurolysis that may include determination of the damage. Both types of treatment may be required simultaneously. Such treatment may be risky due to the proximity of vital structures in the area: arteries, veins, ductus thoracicus, lung apex, airways, oesophagus, and thyroid. The safety is secured by the knowledge of anatomical variability (neural and vascular). Reconstruction in the conditions of cicatricial transformation of surrounding tissue represents a serious problem. The gaps between individual muscles may be filled with fibrotic tissue.

Surgical revision may start from the revision of distal parts of brachial plexus in fossa axilaris by identification of the nerves. If the nerves appear normal, the revision may continue in the proximal direction. If the nerves are located within the cicatrized tissue, peripheral nerves in the proximal part of the arm are cleared up or the brachial plexus is revised distally to m. pectoralis minor downwards up to the deltoidopectoral furrow. Although the confirmation of avulsion by a direct revision of roots is preferred, severe cicatrisation may cause difficulties during the intervention and an increased risk. In such cases, the surgeon may prepare myelographic evidence of avulsion.

Preganglial injuries are accompanied by disruption of nerve roots (especially anterior) or by roots displaced from the spine. This fact leads to retrograde changes in the spine and spine atrophy due to damaged sensory and motor filaments. The re-implantation of torned roots back into the spine was possible only in some cases. Therefore reconstruction using a nerve transfer is necessary in the presence of avulsion.

The aim of neurotization is to achieve reconstruction of the continuity by the transfer of a functional nerve graft to the distal stump of denervated nerve (1, 2, 3, 6).

Transfer should be limited to terminal branches since transfer to trunk or fascicles leads to significant dispersion and the loss of nerve filaments (2).

In adults, it is better to perform extraplexal nerve transfer than intraplexal transfer.

Extraplexal nerve transfer can include C4 root, n. accessorius, intercostal nerves, cervical plexus or n. hypoglossus. They are used for transfer into distal stumps that have lost their spinal roots due to avulsion. Nerves, in the order of importance, are following: n. musculocutaneus, n. suprascapularis, n. axilaris, n. thoracius longus, n. pectoralis, and triceps radial nerves. The reconstruction is following: flexion in the elbow, abduction and exterior rotation of the arm, functional correction of the long arm flexors and restoration of sensitivity on the radial part of arm.

Neurotization of n. musculocutaneous has following indications: 1) avulsion of C5–C6 roots or a total avulsion, 2) up to 5 months after the injury, 3) absence of elbow stiffness, 4) absence of rib fractures, 5) age under 50 (5, 6).

N. musculocutaneous contains approximately 6000 nerve filaments. Intercostal nerves containing about 1000 fibers are used for its re-innervation. About 50 % of them are motor. N. musculocutaneus is dissected from the motor point in m. biceps to its beginning in lateral fascicle. Motor component of intercostal nerves Th4 and Th5 is directly sutured to the motor part of n. musculocutaneous and sensory component with sensory part. If one uses intercostal nerve Th6, an inserted graft is needed. Motor component of Th3 intercostal nerve is transferred with a direct connection to the nerve at the lower end of m. pectoralis major.

Improper arrangement of nerve fascicles in the suture may cause loss of 50 % of motor filaments and is responsible for bad results regarding the use for nerve transfer.

With n. accessorius we have another 2000 nerve filaments available. To avoid the denervation of m. trapezius, n. accessorius is prepared under its proximal branch (5).

Impulses from all intercostal nerves are simultaneous. If two muscles are innervated from different intercostal nerves, they are contracting simultaneously. Therefore antagonistic muscles should not be neurotized by the same donor nerves. If n. intercostalis is not the proper choice (multiple fractures of the ribs, Brown-Sequard syndrome, diaphragm paralysis), n. accessorius or n. hypoglossus may be used for n. musculocutaneous. Motor branches of cervical plexus are utilized for neurotization of n thoracicus longus and the second intercostal nerve for neurotization of thoracodorsal nerve. Contralateral C7 transfer is reserved mainly for neurotization of free muscle grafts since patients are not able to learn the coordination of impulses from contralateral side (4).

The surgical plan is different in case of C7 avulsion and depends on the combination with other injuries. Transfer of cervical sensory nerves to C7 rump was performed in cases where no other lesion has been identified.

In the presence of avulsion of C5–Th1 it is better to neurotize simultaneously n. axilaris and n. musculocutaneous, to neurotize n. thoracicus longus and later arthrodesis of the arm. Reconstruction is much more difficult. Deficit in the arm function is usually severe and the extension of the wrist or the metacarpophalangeal extension is absent. Arthrodesis of the wrist does not provide a solution and is indicated only in cases of plegic arm for cosmetic reasons. In cases where rupture of the upper trunk has been associated, intraplexal nerve transfer was achieved by distribution of the filaments from the upper trunk to the distal rumps of C5, C6 and C7. However, in case of injuries of lower trunks or lower spinal nerves, grafts originating from the lower trunk were distributed mainly to the intermedial trunk and to the upper parts of the lower trunk due to limited recovery of the C8 and Th1 roots.

Intervention using a nerve graft is performed in case of C7 rupture. If the C7 root is intact, extension of the wrist can be sufficient but extension of the fingers requires transfer of the tendon from arm flexors.

Potential benefit of the tendon transfer must be higher than the deterioration or loss of function in the area of graft removal. Tendon transfer also causes reduction or loss of some other function but this has to be lower than the potential benefit. Muscles that were paralyzed after nerve injury and later have recovered are not suitable for tendon transfer since they have reduced strength and (more importantly) they do not have good and independent control. The decision on performing arthrodesis or tenodesis must be done after thorough consideration. Generally, arthrodesis of the wrist should be performed to stabilize the wrist. The effect of the function should be evaluated before the intervention. Tenodesis on the arm may be performed in cases where full strength of the hand squeeze is preserved.

In reconstruction, n. suralis is utilized less frequently in cases of ruptures of the root or more distal parts of the plexus. If the injury is postganglial, the root may be connected to the distal parts by suture or using a nerve graft.

Outcome of the treatment is poorer when grafts are longer then 5 cm. Such treatment is often ineffective due to fibrous block at distal suture or due to graft necrosis that prevents the growth of regenerating axons. The rate of growth of nerve filaments across the graft is reduced by a factor of 1,5–2.

If more grafts are necessary, the medial skin nerve from the arm may be used as well. Only nerves with the dimension of the skin nerves are suitable as nerve grafts.

Ischemic injury accompanied by necrotization and fibrotization may develop in the larger neural stems due to reduced spontaneous revascularization in central parts.

Lesions of brachial plexus can be accompanied by avulsions of motor nerves from the muscles. Rupture of the peripheral nerve is present usually at the site of its terminal branching and at neuromuscular connections. In these cases a direct nerve-muscle neurotization may include a direct transfer of motor nerves to the muscle or the use of the nerve grafts. New motor lamellae are formed in the aneural parts of the denervated muscle. Grafts obtained from the n. suralis can be formed in the aneural part of the denervated muscle. Grafts from n. suralis are preferentially connected to the original nerve or to other suitable nerve. Distal graft ends are divided to several fascicular groups and introduced into the distal parts of the damaged muscle via longitudinal incision. This incision should be performed as carefully as possible. Nerve branches are implanted into a larger area to increase the volume of re-innervated muscle. Epineurium is sutured to the muscular fascia using an 8/0 not-absorbable suture. Fascicles remain in the muscle interstice and do not need a suture. If bleeding is observed during incision of the muscle, a new incision should be performed on another site due to the risk of the formation of cicatrized tissue.

Results

In reconstruction surgery, it may take several years to see the results. It depends on the character of injury and on time period between the injury and intervention.

Critical factors affecting the outcome include the character and extent of the injury, patient's age and the time period between the injury and intervention. In any case, the prognosis of plexus lesions is negatively affected by vascular damage. This reflects not only more severe character of the injuries, but also problematic revision due to cicatrisation especially after vascular reconstructions. Vascular prothesis can leak in the site of anastomosis, causing the formation of rigid fibrotic tissue surrounding later nerve trunks, and accidental damage of the prothesis may cause hardly controllable bleeding.

To improve the outcome, neurotrophic factors must be taken into account, which are effective in children than in adults.

Superior results of plexus treatment are common in cases of neurolysis or treatment of nerve roots C5, C6 while treatment of roots C8 and Th1 are only rarely successful. The results of the surgery in cases of plexus avulsions are also inferior.

In cases of upper root avulsions where medial and lower parts of plexus are preserved, the function of the arm can be reconstituted by adjustment of a shoulder stability and restoration of elbow flexion.

The results are much worse in the presence of total avulsion and subsequent wrist arthrodesis is usually required. Only limited aims can be achieved in cases of total avulsion, e.g. medium arm abduction, shoulder stabilization by the re-innervation of external rotators, elbow flexion and partial restoration of sensitivity to radial fingers. This aim can be achieved by neurotization of n. suprascapularis, axilaris and musculocutaneus with motor nerves and n. medianus with cervical sensory nerves. In the time period of three years, sensory recovery offers a partial protection for the sensitivity of radial fingers.

If a muscle shows only a limited restoration and the strength is too weak to provide useful function, the situation may be improved by a more distal insertion of its tendon. In other cases, the strength may be improved using a combination of two simultaneously innerved muscles, such as biceps and triceps, to increase the mechanical effect. However, an active extension is not possible in these cases and patient can perform the extension of elbow by decreasing a flexion force and enabling a gravitational force.

Adult patients have problems with learning new functions, even in case of a simple elbow flexion. The time period required for learning a new function may be long. It is necessary to evaluate if further reconstruction using a tendon transfer or other procedures will bring some benefits. If it is clear that the improvement in specific functions cannot be expected after a surgical treatment, the reconstruction plan – arthrodesis of the arm or tendon transfer to the forearm – can be performed earlier.

No positive results were observed in cases where surgical treatment has been performed after 9 months.

In neurolysis, immobilization is required for 1–2 weeks and in nerve grafts or neurotization, for 6 weeks. After this period, physiotherapy can start.

Rehabilitation and electrostimulation start three weeks after the intervention. After 6 months, lateral abduction by 90° and dorsal flexion of the arms are applied to prevent rupture of nerve sutures. Patients are controlled regularly in time periods of 3 months.

Patients without an apparent recovery for more than 15 months reached the "status" where no further improvement can be expected. Prophylactic tendon transfers aimed at wrist extension are valuable if they are performed in time. This is true for cases where functional improvements can be expected later. In children, the recuperation starts 7–8 months after nerve grafting, however, 24 months are the maximum period for re-innervation compatible with an effective recovery of muscular functions. Further functional restoration continues up to 3 years.

Complications

The outcome of the treatment may be jeopardized by common complications such as hematoma, wound infection, or wound dehiscence. Reconstruction operations are able to tolerate some of these complications yielding still acceptable results. Another reasons for treatment failure is fibrosis on the distal end of neural graft.

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