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10.1 Magnetic Resonance Imaging for Detecting Root Avulsions in Traumatic Adult Brachial Plexus Injuries: A Systematic Review and Meta-analysis of Diagnostic Accuracy

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Background: Traumatic brachial plexus injuries (BPI) affect 1% of patients involved in major trauma. Magnetic resonance imaging (MRI) is the best indicator of traumatic BPIs although its ability to differentiate root avulsions (which require urgent reconstructive surgery) from other types of nerve injury remains unknown.

Methods: Medline and Embase were searched from inception to August 2020, with no restrictions. Studies of adults with traumatic non-penetrating unilateral brachial plexus injuries were included. The target condition was root avulsion. The index test was pre-operative MRI and the reference standard was operative exploration of the roots of the brachial plexus.

Results: Eleven studies of 275 adults were included (Figure 1). Most patients were males (94%) injured in motorcycle collisions (84%). Most studies were at unclear or high risk of bias with high applicability concerns (Figure 2). At least one root of the brachial plexus was avulsed in 72% of patients but meta-analysis of patient-level data was impossible owing to sparse and heterogeneous data. With the nerve as the unit of analysis, 55% of nerve roots were avulsed; MRI has a mean sensitivity of 93% (95% CI 77%, 98%) and mean specificity of 72% (95% CI 42%, 90%; Figures 3 and 4) for root avulsion. Therefore, on average MRI fails to identify 1 in 14 avulsed nerves and incorrectly classifies 1 in 4 in-continuity nerves as avulsed.

Conclusions: Based on the limited data, MRI has modest accuracy for diagnosing root avulsions following traumatic BPI and operative exploration should remain the diagnostic option.
10.2 Diffusion Tensor Imaging Tractography for Diagnosing Traumatic Brachial Plexus Root Avulsions: A Proof-of-Concept Study

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Background: MRI is the best indicator of traumatic brachial plexus injury (BPI), although its diagnostic accuracy is moderate. Therefore, patients undergo major exploratory surgery or wait months for potential recovery. This study aimed to develop a novel MRI technique (diffusion tensor imaging, DTI), to visualise the normal and injured roots of the brachial plexus.

Methods: Twenty asymptomatic healthy adults were recruited for sequence development. Twelve adults with known (operatively explored) patterns of unilateral traumatic brachial plexus root avulsions were recruited for technique validation. A Siemens system was used to acquire single-shot echo-planar imaging at 3 Tesla, to reconstruct the brachial plexus in 3D by deterministic tractography. Diffusion of water in the nerves is quantified by the eigenvalues (fractional anisotropy [FA] and mean diffusivity [MD]).

Results: DTI tractography reconstructs the normal brachial plexus and root avulsions with high fidelity (Figures 1 and 2, respectively). Compared to healthy nerves roots, the FA of avulsed nerve roots was 10% lower (95% CI 7%, 13%; 0.001; Figure 3) and the MD was 0.32 greater (95% CI 0.11, 0.53; Figure 4). The negative-predictive value of DTI for at least one root avulsion was 100% (95% CI 78, 100), with a specificity of 58% (95% CI 37%, 78%).

Conclusions: DTI tractography appears to reliably reconstruct the normal and injured brachial plexus. The accuracy of this technique in acute injuries is currently being investigated through a multicentred diagnostic accuracy study in the UK.
10.3 Imaging possibilities of the brachial and lumbosacral plexus using advanced magnetic resonance techniques

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Visualization of the brachial plexus (BP) and lumbosacral plexus (LSP) by magnetic resonance imaging (MRI) allows us to obtain detailed information useful in diagnosing and treatment of disorders affecting these complex nerve structures. MR techniques helpful in visualising BP and LSP include conventional methods, MR neurography (MRN), diffuse tensor imaging (DTI) and MR tractography (MRT). MRN provides detailed analysis of anatomical structure, DTI and MRT inform us on the functional integrity of the nerve fibers. With continuing development and improvement of these advanced MR techniques, we can assume their gradual introduction into standard MR protocols.
Use of Processed Human Nerve Allograft in Reconstruction of Brachial Plexus Birth Injuries

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Objective: Describe our experience with processed human nerve allograft in brachial plexus birth injury reconstruction.

Methods: Retrospective review was performed on medical records of patients who underwent brachial plexus reconstruction involving processed human nerve allograft at Nicklaus Children’s Hospital from April 2012 to October 2013. Thirteen patients met inclusion criteria. All operations were performed by the same surgeon.

Results: The patients ranged in age from 6 to 12 months. Seven were female (54%); 6 were male (46%). Seven were affected on the left (54%); six were affected on the right (46%). Nine patients suffered upper plexus injuries (69%); 2 patients sustained extended Erb’s injuries (15%); 2 patients sustained global injuries (15%). Seven patients underwent concomitant spinal accessory to suprascapular nerve transfer (54%). Concomitant autograft was used in 5 cases: sural nerve was used in 4 cases (31%) and cervical plexus was used in 1 case (8%).

The number of processed nerve allografts used in each case ranged from 1-2. The allograft length ranged from 3.0-4.7cm, with average length 4.2cm. The allograft was placed end-to-end in 4 cases (31%) and end-to-side in 9 cases (69%). Donor signal was obtained from C5 and/or C6 nerve roots; recipient sites included the suprascapular nerve, anterior and posterior divisions of the upper trunk and the middle trunk.

Conclusions: Although observed recovery in the patients cannot be exclusively attributed to the use of processed nerve allograft, results of this study suggest that processed nerve allografts may be used in a supplemental fashion for brachial plexus reconstruction.
10.5 Failed repair of a brachial plexus birth injury using processed nerve allografts

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Introduction: Processed nerve allografts (PNAs) have recently been reported to perform well in sensory, mixed and motor defects between 5-50 mm.

Methods: A boy born at 42 weeks presented with a flail upper limb. A cervical MRI performed at 13 days of age, was suggestive of a C8 avulsion. Ruptures of C5-7 roots were found in exploration, which was done at five weeks of age. C8 and T1 were intact. Upper and middle trunks were reconstructed tension free with five 2x20 mm PNA, secured in place with fibrin glue. Wound healed uneventfully without signs of an infection.

Results: There was no recovery of shoulder movements or elbow flexion clinically, nor in EMG performed ten months after surgery. A re-operation was done at 11 months of age, which revealed complete resorption of all five PNA grafts. The pathology report described fibrous and degenerative tissue mixed with unorganized nervous tissue in the resected areas. Reconstruction of the patient’s upper and middle trunks was performed with five 35 to 45 mm long sural nerve grafts. One year after the re-operation shoulder abduction was grade 5 and elbow flexion grade 2 assessed by the Active Movement Scale.

Summary: The reason for resorption of the PNAs is unclear. PNA grafts should be used with caution in peripheral motor nerve reconstructions until the cause and the true frequency of unsatisfactory results is known.
**10.6 Early Results of Nerve Transfers for Restoring Function in Severe Cases of Acute Flaccid Myelitis**

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Introduction: Acute flaccid myelitis (AFM) is a recently recognized illness which causes acute flaccid paralysis in children. It is associated with enterovirus D-68 and A-71, but the exact pathogenesis is unknown, and no medical treatment is available yet.

Objective: Describe early functional outcomes of nerve transfer surgery in a relatively large cohort of patients with AFM.

Methods: Retrospective case analysis of patients with AFM treated with nerve transfer surgery between 2007 and 2018. Surgical criteria were persistent motor deficits after 6 months from onset and available donor nerves. Motor function was evaluated by a licensed occupational therapist using the Active Movement Scale (AMS) preoperatively and during follow-up examinations. Patients with 6 or more months of follow-up were included in the analysis. Insufficient documentation and patients with procedures other than nerve transfers were excluded.

Results: Forty-five nerve transfers were performed in 16 patients with AFM (median of 3 transfers per patient). Eleven patients had a minimum of 6 months follow-up. Nerve transfers to restore elbow function had 87% excellent recovery for elbow flexion and 67% for elbow extension. Finger and thumb extension were full against gravity in one patient (100%). Shoulder external rotation was excellent in 40% of patients and shoulder abduction in only 20%. All nine patients with sufficient data had recovery of shoulder pseudosubluxation.

Conclusion: Patients with AFM with persistent motor deficits after 6 to 9 months after onset may benefit from nerve transfer surgery. Restoration of elbow function was more reliable than restoration of shoulder function.
10.7 Results of 6 median to musculocutaneous nerve transfers to induce active elbow flexion in arthrogryposis

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Background: Arthrogryposis multiplex congenita (AMC) is a rare but disabling disease which affects mainly upper and lower extremities. Patients are often not able to eat unassisted due to elbow contracture and nonexistent active elbow flexion and therefore insufficient hand-to-mouth range of motion. After reporting the optimistic result of a bilateral Oberlin transfer in an arthrogrypotic baby during the last Narakas meeting in Barcelona, I performed another four such transfers in similar cases and would like to report the results after minimum 24 months follow up.

Methods: I selected 4 patients with AMC type 1 (6 extremities) out of 13 newborn patients diagnosed with AMC presented to our hospital from 2011 to 2016 to perform a nerve transfer to induce active elbow flexion within the first year of life. Inclusion criteria were active finger and wrist flexion, limited contracture of elbow joints and evidence of biceps muscle fibers detected by sonography.

Results: I report results of 6 nerve transfers to induce active elbow flexion with a minimum follow up of at least 24 months. In this retrospective study, one extremity reached active elbow flexion motorgrade M5, one M4, three M3, and one M1 24 months after surgery. In the group without nerve transfer, the babies did not develop active elbow flexion or they were able to flex elbow after birth.

Conclusions: This study proofs the concept of nerve transfer in the condition of AMC. Level of evidence 4.
10.8 Surgical treatment for child brachial neuritis

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Brachial neuritis, also known as Parsonage-Turner Syndrome, is a rare and idiopathic disorder, characterized with pain and weakness of upper extremity. The treatment for BN has been challenged for neurologist. From 2010, four cases BN with upper or upper and middle trunk of the brachial plexus were affected were treated with medicine and physical therapy, but no improvements were seen after more than 6 months. Then, a serial of nerve transfers were performed, accessory nerve was transferred to suprascapular nerve, partial ulnar nerve or intercostal nerves were transferred to musculocutaneous nerve, intercostal nerves were transferred to axillary nerve in the meantime for one case. After six months to 2 years follow-up, 40-150 degrees of shoulder abduction, 60 degrees of shoulder external rotation was gained and strength of elbow flexion reached M4. Pathological examination of the suprascapular nerve did not find any special change, except severe inflammatory reaction in the proximal part. According to our experience, if brachial neuritis was treated with medicine without any improvement after 6 months, nerve transfer could be one choice for these patients, the operation should also be conducted within 1 year before the severe muscle atrophy. Based on our experience and the pathological result, we suggest that nerve transfer to the distal part of the recipient nerve may lead to better results.
10.9 Current concepts in plasticity and nerve transfers: relationship between surgical techniques and outcomes

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OBJECTIVE: Neuroplasticity is analyzed in this article as the capacity of the CNS to adapt to external and internal stimuli. It is being increasingly recognized as an important factor for the successful outcome of nerve transfers. Better-known factors are the number of axons that cross the coaptation site, the time interval between trauma and repair, and age. Neuroplasticity is mediated initially by synaptic and neurotransmitter changes. Over time, the activation of previously existing but lowly active connections in the brain cortex contributes further. Dendritic sprouting and axonal elongation might also take place but are less likely to be prominent.

METHODS: The authors reviewed different factors that play roles in neuroplasticity and functional regeneration after specific nerve transfers.

RESULTS: The authors found that these different factors include, among others, the distance between cortical areas of the donor and receptor neurons, the presence versus absence of preexisting lowly active interneuronal connections, gross versus fine movement restoration, rehabilitation, brain trauma, and age.

CONCLUSIONS: The potential for plasticity should be taken into consideration by surgeons when planning surgical strategy and postoperative rehabilitation, because its influence on results cannot be denied.
Increased brain activation during motor imagery suggests central abnormality in Neonatal Brachial Plexus Palsy

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Neonatal Brachial Plexus Palsy (NBPP) may lead to permanent impairment of arm function. As NBPP occurs when central motor programs develop, these may be ill-formed. We studied elbow flexion and motor imagery with fMRI to search for abnormal motor programming. We compared the cortical activity of adults with conservatively treated NBPP to that of healthy individuals stratified for hand dominance, using fMRI BOLD tasks of elbow flexion and motor imagery of flexion. Additionally, resting-state networks and regional gray matter volume were studied. Sixteen adult NBPP patients (seven men; median age 29 years) and sixteen healthy subjects (seven men, median age 27 years) participated. Cortical activation was significantly higher in patients during flexion imagery compared to healthy individuals and it increased with lesion extent and muscle weakness. The contralateral and ipsilateral premotor cortex, and the contralateral motor cortex showed stronger activity during imagined flexion in the right-handed NBPP subjects compared to healthy individuals. Activity patterns during actual flexion did not differ between groups. No differences in resting-state network connectivity or gray matter amount were found between the groups. NBPP affected imagined but not actual elbow flexion, suggesting an impairment.
10.11 A Quantitative Analysis of the Sensory and Motor Fibres of the Major Nerves in the Human Arm

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Introduction: Any surgical nerve reconstruction must take into account quantity of individual nerve fibres at any given level of injury. To date, however, literature on qualitative and quantitative assessment of axons of the peripheral nerves of the upper extremity is scarce. The aim of the present study is to present the total number of motor fibres of the brachial plexus and its corresponding branches.

Material and Methods: Nerve samples have been harvested from 9 organ donors immediately after death. From 8 incisions ranging from the neck to the wrist a total of 36 nerve samples were gained per organ donor. Immunofluorescence was applied to visualize the specific structure of interest within the nerve cross section. Antibody against neurofilament served to determine the total amount of myelinated and unmyelinated axons. Antibody against choline acetyltranferase (ChAT) was used to detect cholinergic/motor fibres.

Results: Data of all major nerves and their branches in the arm and forearm are presented. Around one tenth of all axons in a mixed peripheral nerve are cholinergic fibres (motor fibres). In a pure motor nerve (thoracodorsal nerve) one third of the axons are cholinergic. Furthermore, a pure motor cranial nerve (accessory nerve) also has an afferent fibre proportion. As expected, sensory nerves do not contain axons exhibiting ChAT immunoreactivity.

Conclusion: Here we present for the first time a quantitative analysis of all cholinergic fibres of the brachial plexus and its consecutive nerves. This data will help in surgical planning and improve the functional outcome after nerve repair.
10.12 Factors Associated with Outcomes After Nerve Transfers: A Pooled Analysis

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Intro:
Outcomes after common nerve transfers are highly variable. Existing literature has shown age, time from injury to surgery, and number of nerves transferred to be associated with outcomes after nerve transfer. We aim to confirm existing factors associated with postoperative outcomes and determine potentially novel factors that influence results of spinal accessory nerve (SAN) to suprascapular nerve (SSN) transfer, Oberlin transfer/double fascicular transfer, and intercostal nerve (ICN) to musculocutaneous nerve (MCN) transfer via pooled analysis.

Methods:
A systematic review of the literature was conducted according to PRISMA guidelines utilizing multiple biomedical databases. Two independent reviewers screened titles and abstracts to determine inclusion of studies in this pooled analysis. The primary outcome measure was shoulder abduction/external rotation and elbow flexion medical research council (MRC) scores. We assessed the association between postoperative MRC scores and the following factors: age, time from injury to surgery, extent of brachial plexus injury, and number of nerves transferred.

Results:
Seven studies (88 patients) were included in the SAN/SSN transfer study. Eighteen studies (209 patients) were included in the Oberlin transfer/double fascicular transfer study. Fifteen studies (124 patients) were included for the ICN/MCN transfer study. Extent of injury was the only significant predictor of poorer shoulder abduction outcomes in SAN to SSN pooled analysis (OR:0.55, p=0.019). Double fascicular transfer was a predictor of superior postoperative outcomes relative to Oberlin transfer in patients undergoing MCN neurotization (OR:3.021, p=0.009). Greater delay from injury to surgery was the only significant risk factor for poor outcomes in the ICN to MCN transfer pooled analysis (OR: 0.845, p=0.039).

Conclusion:
Outcome after SAN to SSN transfer is negatively affected by extent of injury independent of other factors. Increased number of nerves transferred in double fascicular transfer is associated with superior results relative to Oberlin transfer; however, transferring more intercostal nerves is not associated with improved outcomes. Factors that affect outcomes after nerve transfer are more complex than commonly believed.