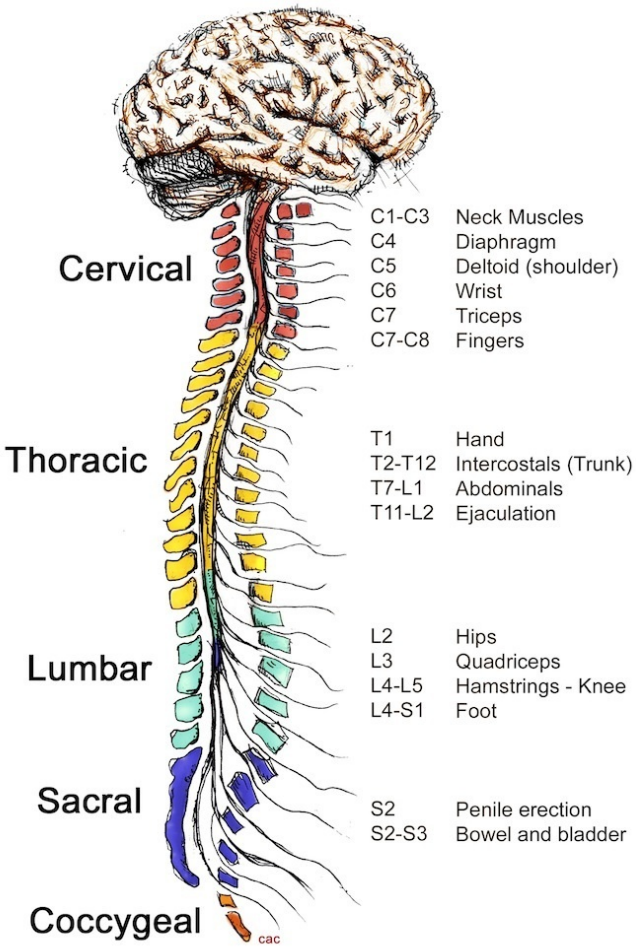
Spinal Cord Monitoring, Nerve Conduction Studies and re-wiring the upper limb

Colin Shirley MB ChB (Hons) MRCP (Lond) MRCP (UK)
Consultant Clinical Neurophysiologist
Queen Elizabeth Hospital, Edgbaston, Birmingham

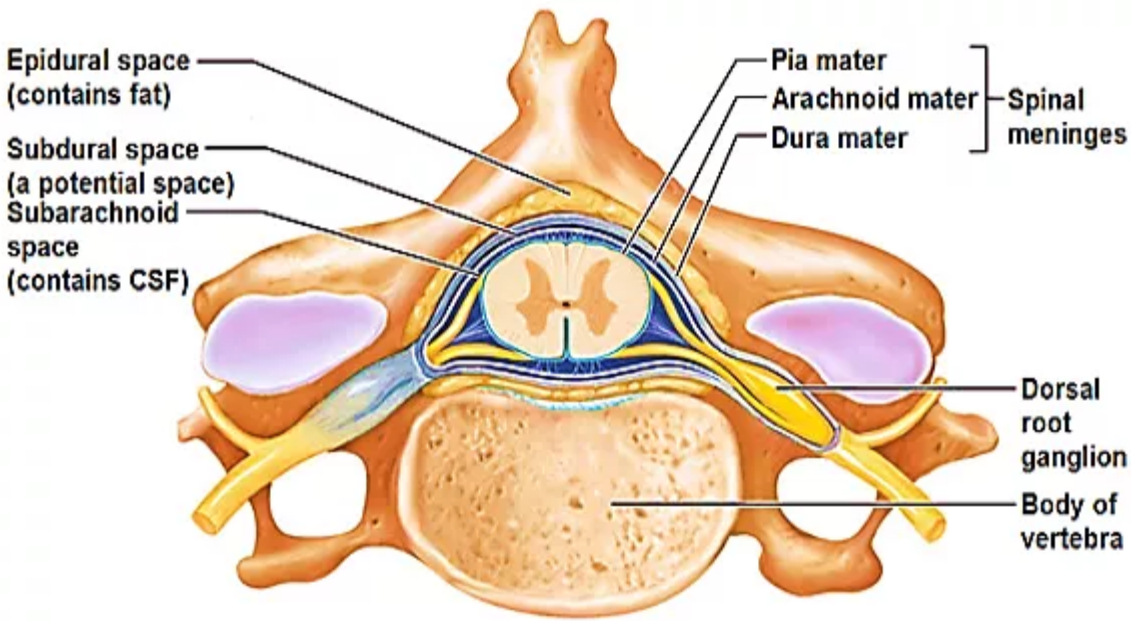
Content

- To briefly review neuro anatomy
- Discuss the principles of spinal cord monitoring, the uncertainties and pitfalls
- Briefly review the role of nerve conduction studies in medico-legal assessments
- Look at the potential evolving role of nerve transfer surgery in restoring upper limb function

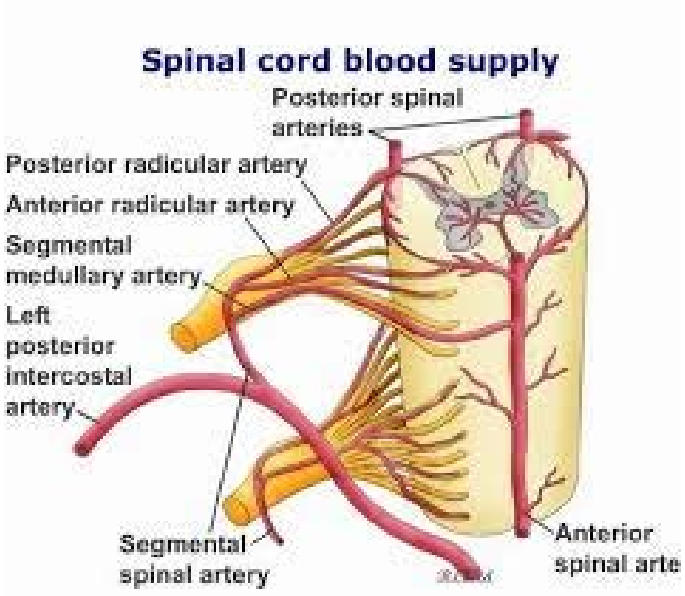
Overview of Neuro-anatomy



Spinal Neuro-anatomy



Spinal Anatomy



Potential sites of injury

- Spinal nerve roots – pain, loss of motor and sensory function, if single level may have limited effect on function (depending on level and severity)
- Spinal Cord – Can be partial or complete results in loss of function below the affected spinal level – causes upper motor neurone signs – spasticity below the affected level, loss of bladder and bowel and sexual function
- Cauda Equina – Below the level of the cord, causes flaccid weakness in the legs and loss of bladder, bowel and sexual function (depend on severity)

Broad sub-types of spinal procedures

- Disc/bony surgery – remove material that compresses roots/cord eg prolapsed inter-vertebral discs decompress nerve roots or the cord itself
- Spinal deformity – usually major surgery large surgical exposure – multiple points of fixation usually with pedicle screws, rods inserted down the side of the spinal column to correct scoliosis; also includes listhesis surgery
- Intra-dural pathology – tumour inside the “sack” surrounding the spinal cord – can be extra-medullary ie outside of the spinal cord or intra-medullary ie tumour arising within the cord

Disc/Bony decompressive Surgery

- Usually does not require any type of neuro-monitoring

Deformity and listhesis surgery

- Good evidence base exists that effectively mandates that scoliois surgery is monitored (except where there are profound neurological deficits or where monitoring cannot be performed for some other reason)
- When a monitoring alert occurs there are options available – remove rods, remove screw, undo de-rotation, increase BP, close and perform second stage procedure etc

Intra-dural spinal pathology

- Less of an evidence base
- Far rarer disease
- There is an established role of NIOM for predicting a neurological deficit
- Difficult to provide high quality evidence that it prevents neurological injury
- No/few high quality studies to show the ability of NIOM to prevent neurological injury but inherently difficult clinical trials to perform

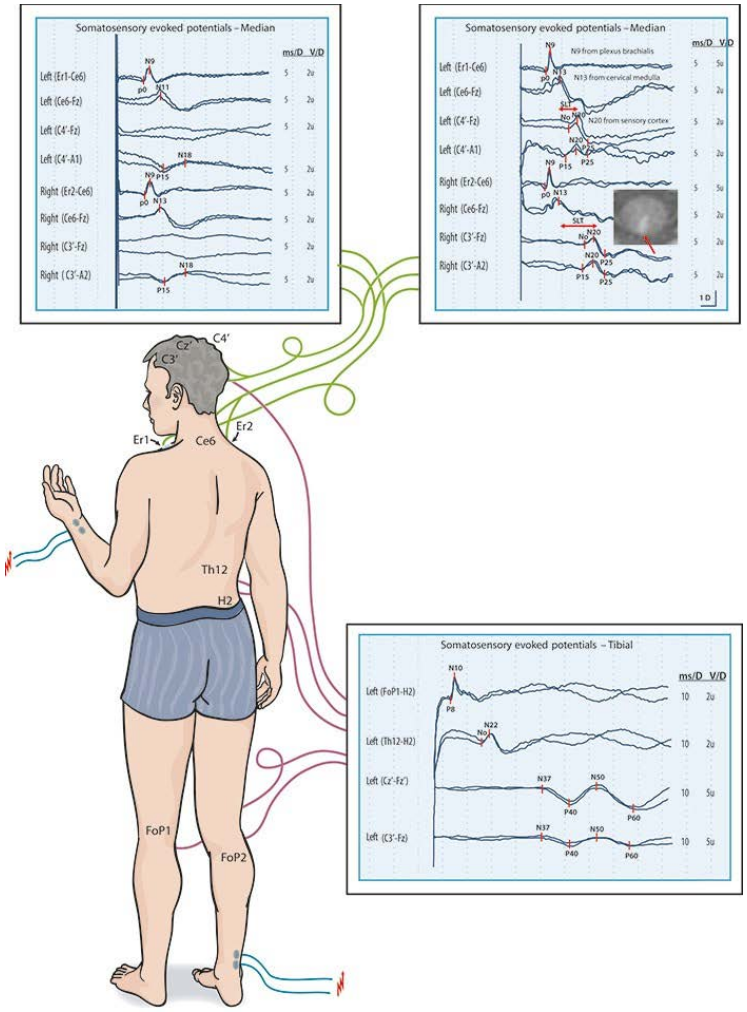
Intra-dural Pathology

- Difficult to define if better or worse tumour clearance with NIOM
- Difficult decision making – when to stop operating – once you've gone too far there may be few or no options to reverse "your last move"

Types of monitoring

- Somato-sensory evoked potentials
- Stimulate peripheral nerve, send a volley up dorsal columns, record at brain
- Can be performed nearly all the way through the procedure
- Increase in time taken for volley to travel to the brain or decrease in size of response is an alert

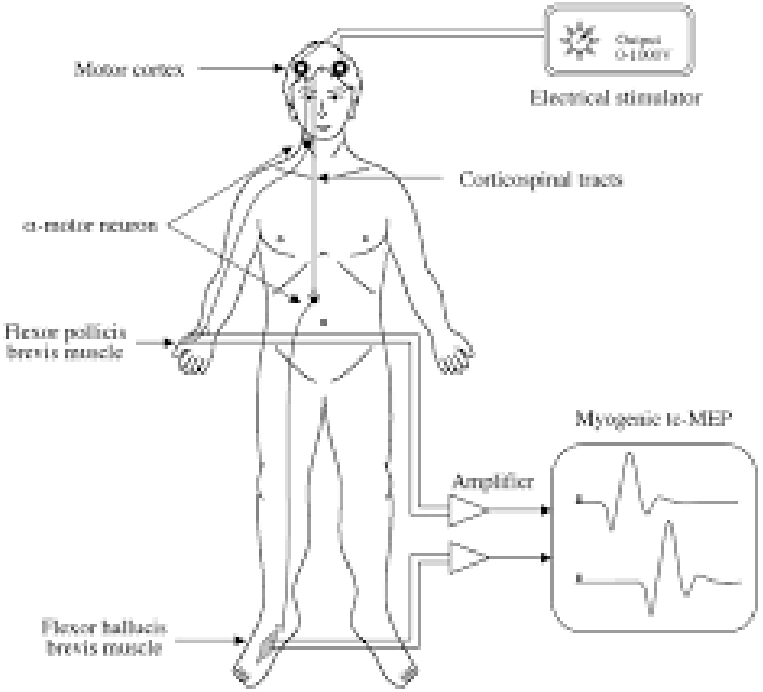
SSEP


Somatosensory evoked potentials – Median
ms/D V/D
Left (Er1-Ce6)
Left (Ce6-Fz)
Left ((C4'-Fz)
Left ((C4'-A1)
Right (Er2-Ce6)
Right (Ce6-Fz)
Right (C3'-Fz)
Right (C3'-A2)
N9
p0
N11
N18
P15
N13
Somatosensory evoked potentials – Median
N9 from plexus brachialis
N13 from cervical medulla
N20 from sensory cortex
SLT
N20
P25
1 D
C4'
Cz'
C3'
Er1
Ce6
Er2
Th12
H2
FoP1
FoP2
Somatosensory evoked potentials – Tibial
Left (FoP1-H2)
Left (Th12-H2)
Left (Cz'-Fz')
Left (C3'-Fz)
N10
P8
N22
N37
N50
P40
P60

Motor Evoked potentials

- Large electrical stimulus over the motor area of the brain
- Sends a volley down motor (cortico-spinal tracts)
- Record responses from upper and lower limb muscles.
- Drop in size of response, increase in time taken for conduction and need for increased stimulus intensity can be used as alert

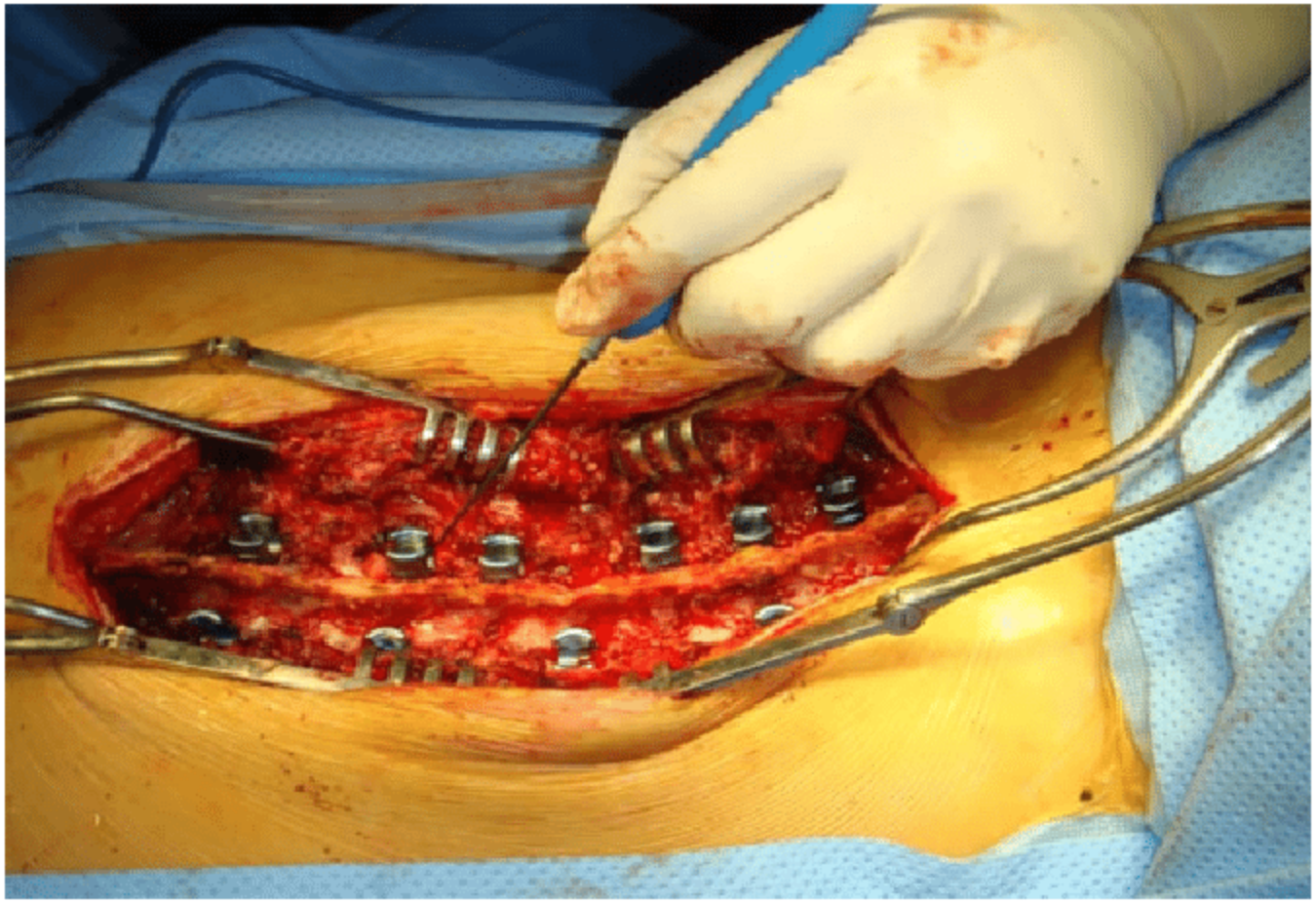
MEP


Motor cortex
Electrical stimulator
Corticospinal tracts
α-motor neuron
Flexor pollicis brevis muscle
Myogenic tc-MEP
Amplifier
Flexor hallucis brevis muscle

Pedicle Screw Monitoring

- Screws are inserted into bony pedicles to act as points of fixation for rods
- Screws can be misplaced
- Up or down may injure roots
- Towards the mid-line may enter spinal canal and injure cord
- Pedicle screw monitoring may help in detecting medial breach but draw back as to when a breach is significant
- Intra-operative CT should make use of pedicle screw monitoring unnecessary

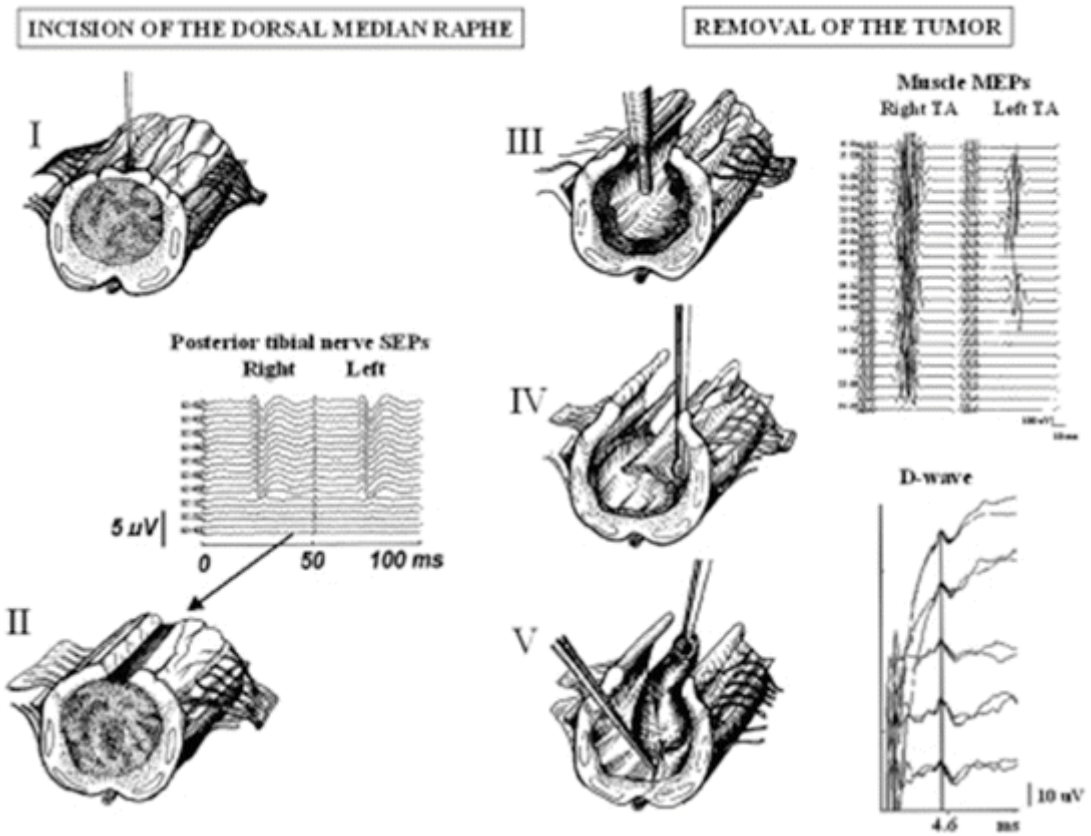
Pedicle Screw Monitroing



D-wave monitoring

- Measures evoked responses directly from the spinal cord
- Useful in intra-medullary tumour surgery
- Allows near continuous monitoring of motor tracts in spinal cord as the patient doesn't "jump"

D-wave monitoring and Intra-Medullary Surgery



Neuro Monitoring alerts

- Various types of alerts
- Increase in the time taken to conduct the signal (latency)
- Decrease in the size of the response (amplitude)
- Increase in the stimulus needed to obtain the same response
- Some discussion as to which precise alert to use – pro's and con's to certain criteria – usually a trade off between to many false negatives and false positives

Pit falls and controversies of spinal IOM

- Operating theatres are difficult electrical environments – need to try to optimise signals, difficult to negotiate with theatre team to turn off devises that cause interference.
- Interference can be impossible to eliminate but can cause major problems with reliable monitoring – what to do? – proceed or cancel case?
- Issue of consent – a patient consents to undergo spinal deformity surgery – monitoring is not optimal – is consent then still valid? – not so much a problem in children as the parents can be asked but a significant problem in adults.
- Mistaking artefact for genuine responses (requires experience)
- What alert criteria to use – too many alerts – stops too many operations
- Misinterpreting data
- Stressful environment – “we need to get on”
- Poor communication between monitorist, anaesthetist and surgeon

Training and Workforce in Spinal NIOM

- Surprisingly no nationally agreed training program
- Historically entry to the profession is from various different backgrounds eg clinical physiologists (formally referred to as neurophysiology technicians), medical physics, academic neuroscientists with additional local training, machine manufacturer representatives
- Usually very little medical consultant oversight in many centres
- Not defined as to what is the required training
- No formal examination and no state register
- Some guidelines exist for spinal deformity (ANS/BSCN) but relatively “broad” guidelines

Potential risks of spinal IOM

- Reported small risk of intra-operative seizure
- Tongue bite injury and oral cavity soft tissue injury from MEP jaw muscle activation
- Patient's should be consented for these potential complications

Nerve Conduction Studies and Electromyography – What are they

- NCS Uses small electrical pulse to “test the wiring” – for peripheral nerves
- Assesses peripheral nerves and “nerve plexuses”
- EMG – involves needle insertion into targeted muscles, helps determine if there has been recent nerve injury to the sampled muscle
- By combining nerve conduction studies and EMG, helps define the site and severity of the nerve injury and can track nerve recovery
- NCS/EMG is generally the preferred technique for assessing peripheral nerves more than imaging (Eg MRI or USS) – but imaging does have a role in selected cases

NCS/EMG – types of conditions they may be useful for in PI/CN cases

- Help to demonstrate nerve compression eg after fracture
- Help demonstrate nerve injury from direct trauma (eg blunt trauma, crush or penetrating injury)
- Help demonstrate brachial plexus injuries following eg shoulder dislocation– especially high velocity/ energy injury(or reduction of shoulder dislocations)
- Help objectively demonstrate nerve injuries caused eg by surgical procedures

Evolving Role of Peripheral Nerve Transfer Surgery in restoring upper limb function

- The technique of nerve transfer is relatively well established but technically challenging and performed only in a few centres nationally
- Principle is to take peripheral nerve fibres from a functioning muscle or part of muscle that has either expendable nerve supply (redundancy) or an expendable muscle head and transfer it to a muscle that has lost it's nerve supply
- Re-innervation can take time, therefore the effects is not immediate

- The role of nerve transfer surgery to improve upper limb function is in evolution but some early encouraging signs

Functional Effects of Spinal Cord Injuries

- Higher complete injuries – eg cervical injuries at C2/3 will result in loss of motor and sensory function in whole of upper ad lower limbs as well as loss of diaphragm function and inter-costal muscles of respiration
- Lower cervical levels begin to offer opportunities for reconstruction
- The lower the cervical levels the more options as more nerve become available for transfer

Practical difficulties with poor upper limb function - examples

- Inability to self-feed
- Limitations of operating mobility aids eg motorised wheel chairs
- Limitation to use electronic devices and phones
- Generally limits ability to self care – greater dependency

“Traditional” Management of Spinal Injury rehabilitation

- Good medical management to treat complication
- Prevention of complications of immobility (eg pressure sores, infection etc)
- Use of devices to improve function
- Treatment of spasticity with drugs, botox, orthoses etc
- Tendon transfer relatively established practice (Involve transferring a muscle tendon that is functioning to re-establish relatively crude upper limb movement

Principles of nerve transfer surgery in spinal cord injuries

- In spinal cord injury at the level of the cord injury and below the level of the injury there will be partial or complete loss of sensory and motor function
- The injury is often asymmetrical due to the mechanism of injury
- The higher the anatomical level of the injury, the loss of function is generally greater

Nature of Spinal Cord Injuries

Upper Limb Reconstruction in Tetraplegia

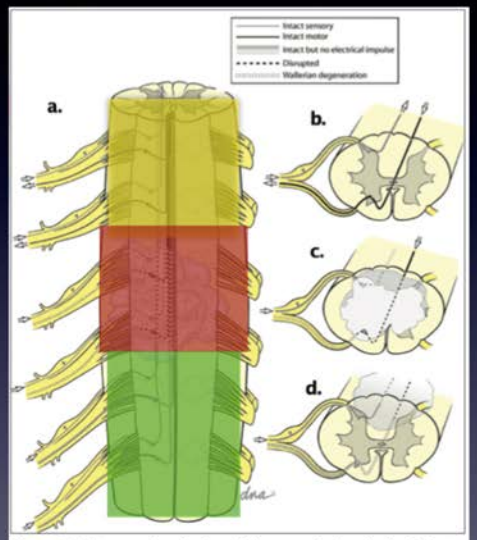


Figure 9: (a) traumatic spinal cord injury results in an indiscriminate disruption of the white and gray matter at and adjacent to the site of trauma, producing three regions of the CNS: (b) the supralesional segment, which retains normal control of its associated peripheral nerves; (c) the injured metamere, which is the site of the cord suffering actual tissue disruption; and (d) the infralesional segment, which often retains anatomical integrity but suffers from a loss of descending input from above. Recognizing which of these three conditions affects the particular muscles of interest allows one to develop an effective reconstructive neurosurgical intervention

- Three spinal cord zones:
  - Supralesional segment
    - Intact zone
    - Volitional control
    - Normal strength and reflexes
  - Injured metamere
    - Loss anterior horns cells
    - Axonal degeneration
    - Behaves like a PNI with MEP degeneration
  - Infralesional sement
    - Anatomical integrity
    - Loss descending inhibitory synapses
    - Intact reflex pathway
    - Late nerve transfer possible?

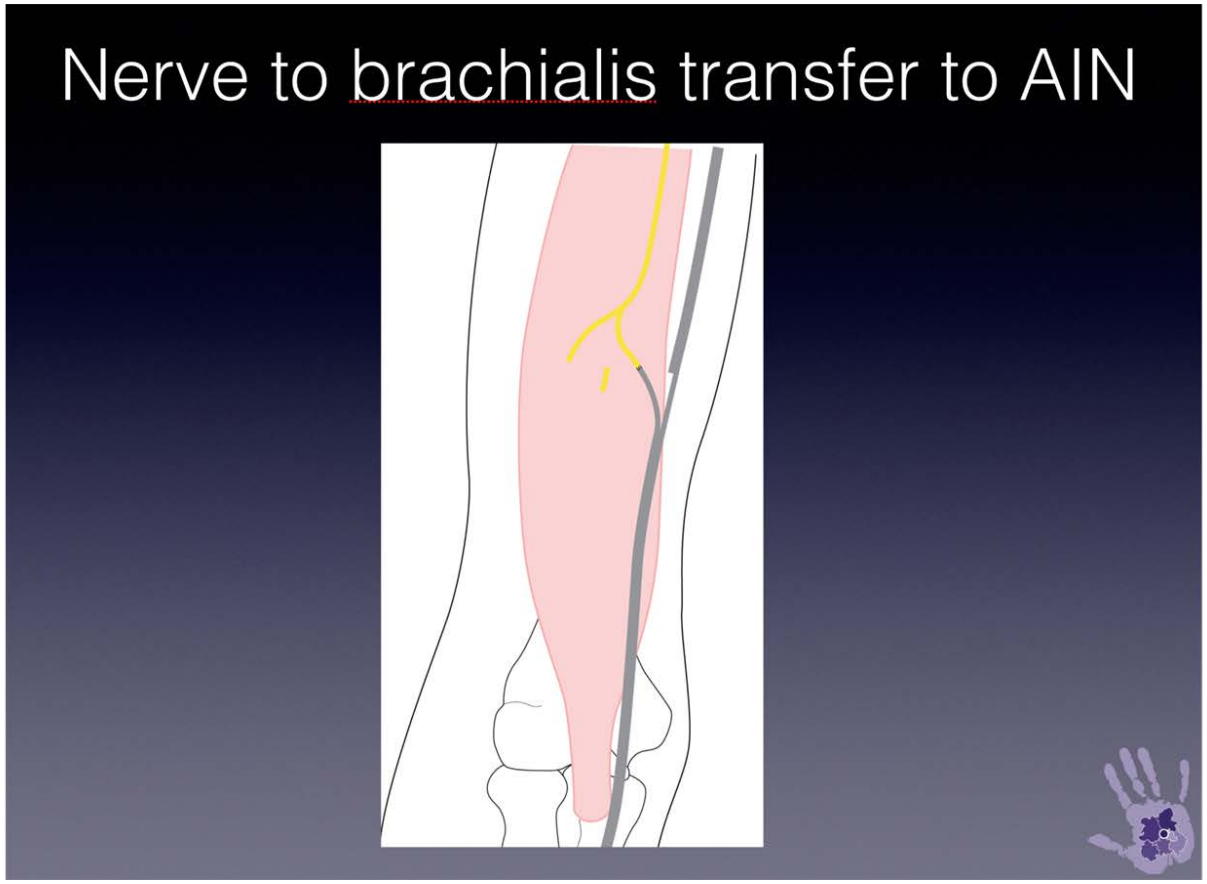
Goal Setting

- Patient needs to be realistic about likely outcomes
- The procedure will not usually restore function to it’s previous level
- The procedure will only restore upper limb function but not lower limbs function
- Still a potentially very meaningful improvement in function

Patient selection

- Careful assessment by surgeon, therapist and neurophysiologist
- Aim to see whether suitable donor and recipient muscles can be identified and plan rehab strategy
- Discuss with the patient what their goals are, ensure they are realistic in their expectations including potential failure of treatment and that this is an evolving application of nerve transfer surgery
- Spasticity – have a plan as to how to treat this or harness it

The procedure of nerve transfer



Practical Difficulties of Nerve Transfer Surgery in Tetraplegic patients

- Patients may need to have more intensive nursing supervision post-op (ITU/HDU) due to pressure sores and respiratory and cardiac complications
- Funding via NHS tariff may be difficult and individual funding requests can be difficult and lengthy if appeals against refusal
- ? Role for claims for funding this treatment through PI claims against insurers
- Some difficulty in the technique being perceived as “experimental” particularly by spinal rehabilitation teams, many patients are very motivated to see what sort of functional gain they may be able to achieve and have often proactively approached the lead nerve injury surgeon
- Spasticity may limit functional gains and need specific treatment
- Important to measure outcomes and adverse effects from this program

Patient Example

- Patient’s case was published in the national press
- Cervical spine injury
- Complex multiple nerve and tendon transfer procedures performed
- Restored upper limb function to the extent that now able to use a self propelled wheel chair, self feed and use and ipad
- Functional outcomes met

Summary

- Neuro-intra-operative monitoring has some firmly established roles (Scoliosis surgery)
- There is generally an evolving expectation that NIOM is an expected standard of care in other types of spinal neurosurgery (and cranial neurosurgery) but the firm robust evidence base to mandate its use is yet to be demonstrated (difficult to conduct clinical trials) – complex medico-legal argument can arise based around this and the principle of patient's being offers all available options and alternatives
- Generally a lack of professional UK guidelines beyond scolisosis surgery
- Still likely to be variation in practice with the use of NIOM in the UK between centres and between surgeons

Summary

- Nerve Conduction studies/EMG can help delineate peripheral nerve and plexus injuries and can be helpful in demonstrating nerve recovery or lack of recovery objectively
- NCS/EMG can be useful alongside clinical examination in establishing a tetraplegia patient's suitability for "upper limb re-wiring"
- Nerve transfer surgery in restoring upper limb function in tetraplegia is an evolving technique which need to performed as part of a comprehensive programme with assessment of outcome measures but some early encouraging signs

Thank you, Any questions?