Post CVA neurological stiffness

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- Stiffness
- CVA
- CVA to stiffness
- Treatment
- Take Home message

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What is Stiffness?

- **Stiffness**
  - …the rigidity of an object — the extent to which it resists deformation in response to an applied force.
  - …the complementary concept is flexibility or pliability: the more flexible an object is, the less stiff it is.

What is Stiffness?

- Stiffness: a term used to describe **the force needed to achieve a certain deformation of a structure.**
- *"Stiffness" = "Load" divided by "Deformation",*

$$Stiffness = \frac{Load}{Deformation}$$

…can be a force, a moment, a stress or a combination of some of these physical variables acting on the structure

…the actual geometrical configuration of the elastic structure is different from the original "unloaded" reference configuration …is always a comparison of two different configurations of a structure.

Baumgart E. **Stiffness--an unknown world of mechanical science?** *Injury. 2000 May;31 Suppl 2:S-B14-23*

What is Stiffness?

- **Joint Stiffness**
  - **…pain and discomfort in a joint, causing difficulty in movement**
  - …can result from medical conditions such as arthritis or from injury, especially when there is protective spasm of the surrounding muscles.
  - …unexplained joint stiffness requires medical assessment and investigation.

What is Stiffness?

- Stiffness can be defined as limited ROM that affects a patient's ability to perform activities of daily living

Bong MR, Di Cesare PE. Stiffness after total knee arthroplasty. J Am Acad Orthop Surg. 2004 May-Jun;12(3):164-71.

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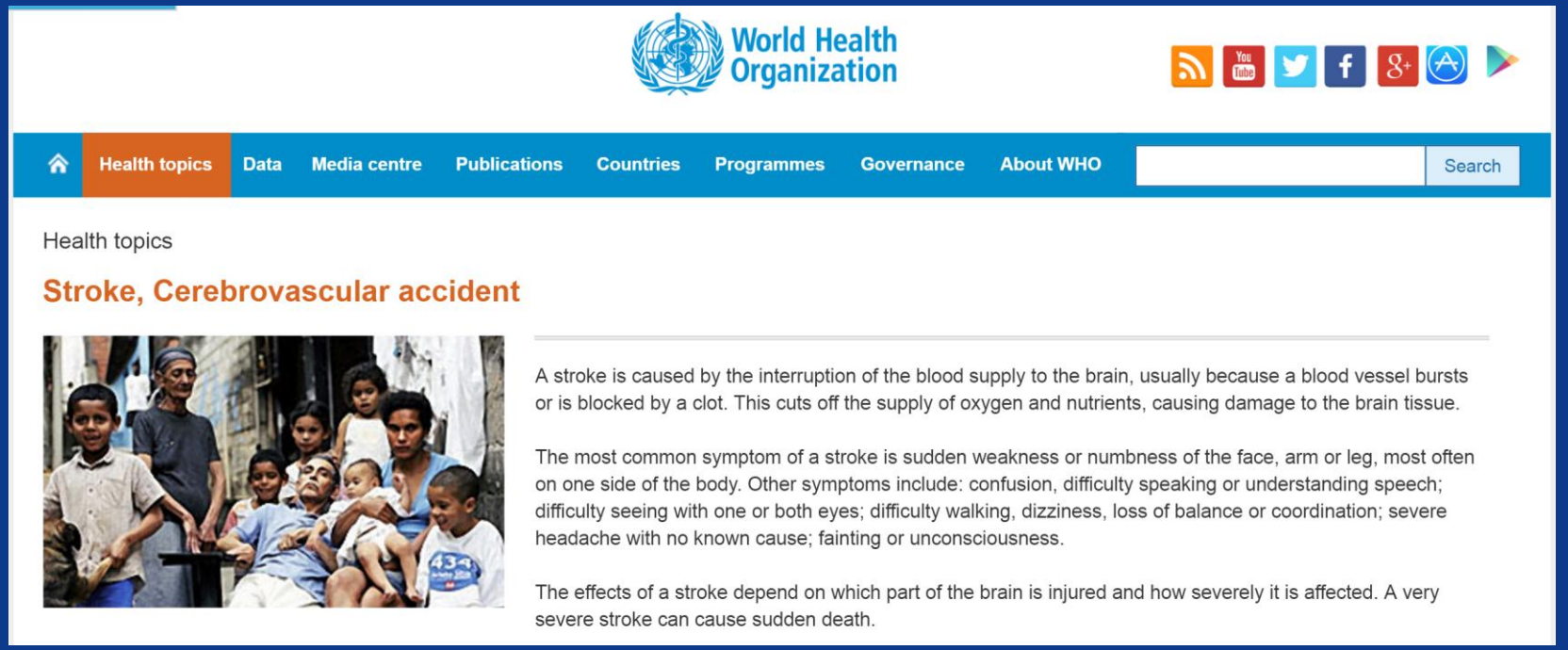
What is a CVA?

Stroke, Cerebrovascular accident

- A stroke is caused by the interruption of the blood supply to the brain, usually because a blood vessel bursts or is blocked by a clot. This cuts off the supply of oxygen and nutrients, causing damage to the brain tissue.



Central nervous system infarction

…brain, spinal cord, or retinal cell death attributable to ischemia, based on neuropathological, neuroimaging, and/or clinical evidence of permanent injury

- Can be:
  - …**ischemic stroke** specifically refers to central nervous system infarction accompanied by overt symptoms
  - …**silent infarction** by definition causes no known symptoms
  - …also broadly includes **intracerebral haemorrhage** and **subarachnoid haemorrhage**

Sacco RL, Kasner SE, Broderick JP, Caplan LR, Connors JJ, Culebras A, Elkind MS, George MG, Hamdan AD, Higashida RT, Hoh BL, Janis LS, Kase CS, Kleindorfer DO, Lee JM, Moseley ME, Peterson ED, Turan TN, Valderrama AL, Vinters HV; American Heart Association Stroke Council, Council on Cardiovascular Surgery and Anesthesia; Council on Cardiovascular Radiology and Intervention; Council on Cardiovascular and Stroke Nursing; Council on Epidemiology and Prevention; Council on Peripheral Vascular Disease; Council on Nutrition, Physical Activity and Metabolism. **An updated definition of stroke for the 21st century: a statement for healthcare professionals from the American Heart Association/American Stroke Association**. *Stroke. 2013 Jul;44(7):2064-89.*

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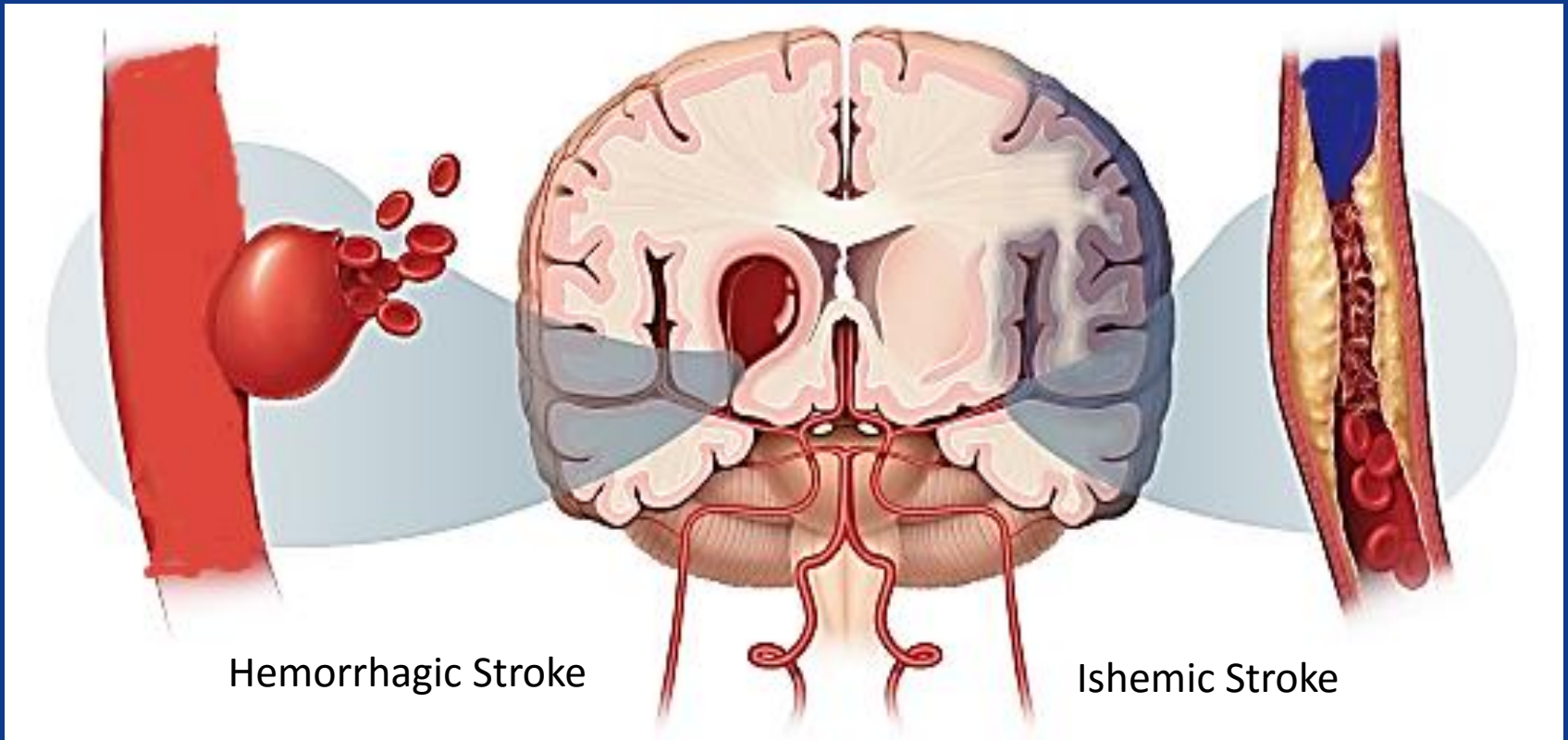

Hemorrhagic Stroke
Ishemic Stroke

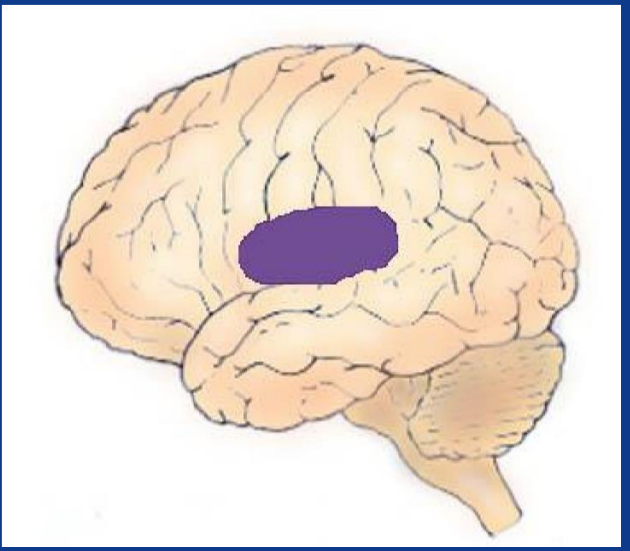
Recovery

- **Spontaneous or Intrinsic Neurological Recovery**
  - recovery of neurological impairments
  - is often the result of brain recovery/reorganization
  - it has been increasingly recognized as being influenced by rehabilitation
- **Functional or Adaptive Recovery**
  - improvement in mobility and activities of daily living
  - it has long been known that it is influenced by rehabilitation

Upper Motor Neuron Lesion

- …a lesion of the neural pathway above the anterior horn cell

  of the spinal cord or motor nuclei of the cranial nerves



Upper Motor Neuron Syndrome

- …the change in motor control that occurs after an upper motor neuron injury

- Characteristics…

  …the presence of spasticity and other forms of involuntary muscle overactivity, voluntary weakness, and a variety of motor control abnormalities that **impair the regulation of voluntary movement**

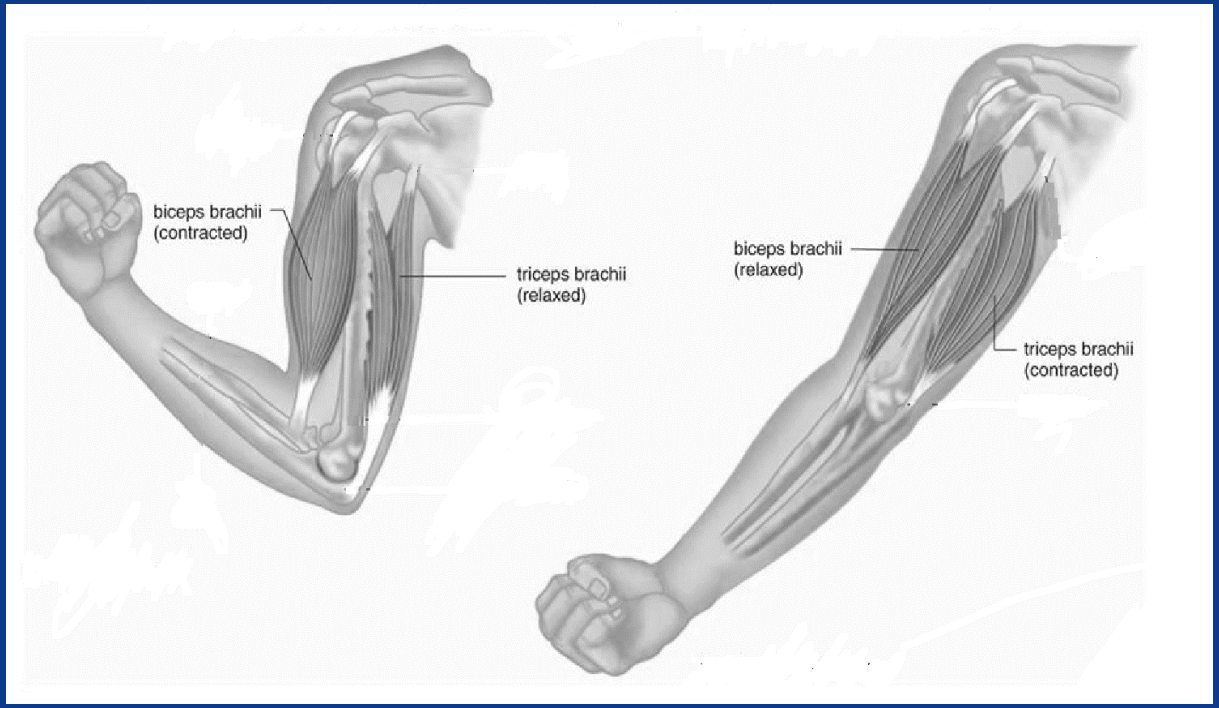
Upper Motor Neuron Syndrome

Positive signs	
Increased tendon reflexes	Result from hyperexcitability of the stretch reflex
Clonus	Series of involuntary, rhythmic, muscular contractions and relaxations due to a self re-excitation of hyperactive stretch reflexes in the affected muscle
Positive Babinski sign	Extension of the big toe, while the other toes fan outwardly in response to rubbing of the sole of the foot. It indicates a lesion of the corticospinal tract
Spasticity	Muscle hypertonia during movement (active or passive), dependent upon velocity of muscle stretch
Extensor/flexor spasms	Spasms occur spontaneously or in response to stimulation (movement of the leg, change of position). The most common pattern of flexor spasm is flexion of the hip, knee and ankle
Spastic co-contraction (during movement)	Agonist and antagonist muscles co-contract simultaneously inappropriately and thus disrupt normal limb movement. This is due to the perturbation of the spinal reflexes that contribute to reciprocal innervation
Associated reactions and other dyssynergic stereotypical spastic dystonia	Remote form of synkinesis due to a failure to inhibit spread of motor activity (e.g. flexion of the elbow simultaneously to flexion of the hip during walking)

Upper Motor Neuron Syndrome

Negative signs	
Muscle weakness	Muscles have lower strength due to the loss of corticospinal drive
Loss of dexterity	Loss of hand precise movements, such as opposition of the thumb due to a weakness of the intrinsic and extrinsic hand muscles
Fatigability	Greater effort required to perform a movement leading to tiredness

Extensors **Flexors**



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Spasticity

- ……'a motor disorder characterized by a velocity dependent increase in tonic stretch reflexes (muscle tone) with exaggerated tendon jerks, resulting from hyperexcitability of the stretch reflex, as one component of the upper motor neuron syndrome'

Lance J. **Spasticity: disorders motor control.** *In: Feldman RG, Young RP, Koella WP editors. Symposium synopsis. Miami, FL: Year Book Medical Publishers*; 1980

- Clinically spasticity manifests as:
  - …an increased resistance offered by muscles to passive stretching (lengthening)
  - …is often **associated with** other commonly observed phenomenon like clasp-knife phenomenon, increased tendon reflexes, clonus, and flexor and extensor spasms

Mukherjee A, Chakravarty A. **Spasticity mechanisms - for the clinician**. *Front Neurol. 2010 Dec 17;1:149*

- **Spasticity**
  - …disordered sensorimotor control

    presenting as **intermittent or sustained involuntary activation of muscles**’
  - …it is a frequent symptom of common neurological disorders

    multiple sclerosis and **stroke**
  - …Spasticity varies from

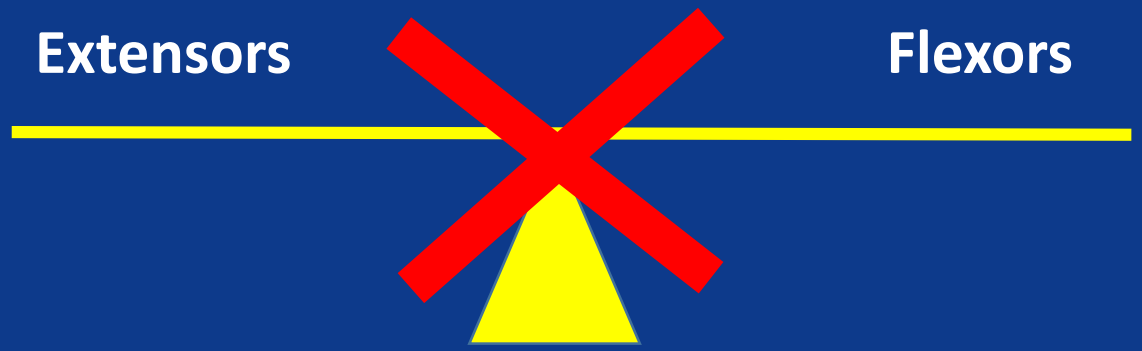
    a clinical sign with no functional impact

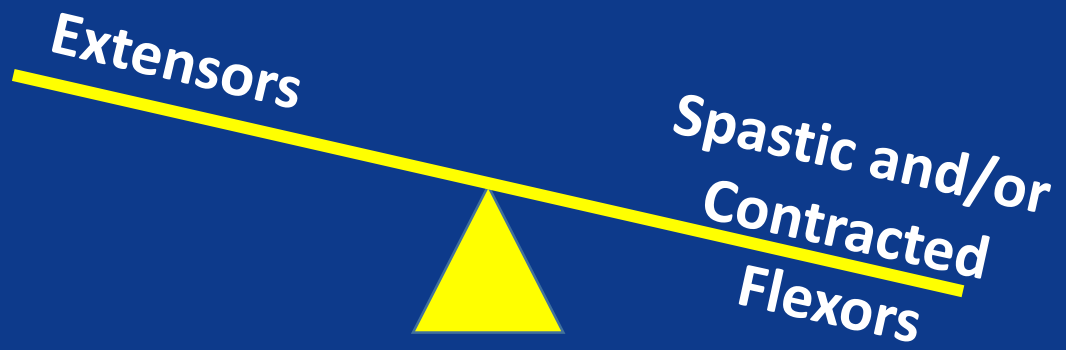
    a gross increase in tone interfering with mobility, transfers and personal care.
  - …untreated, it can cause shortening of muscles and tendons, leading to contractures
  - …some patients depend on their spasticity to stand, walk and transfer or sit upright

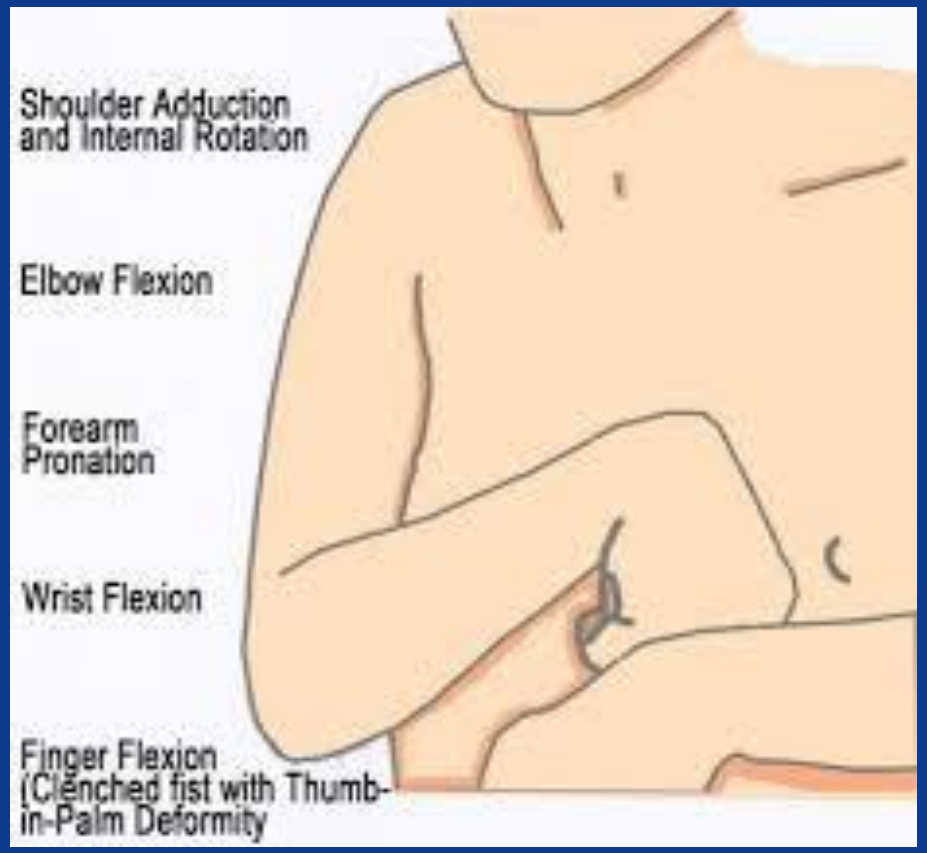
- Features of Spasticity
  - **Increased tone**
  - **Clonus**
    - is the phenomenon of involuntary rhythmic contractions in response to sudden sustained stretch.
  - **Spasms**
    - are sudden involuntary movements that often involve multiple muscle groups and joints.
  - **Spastic dystonia**
    - is tonic muscle overactivity that occurs without any triggers.
    - Spastic dystonia can lead to contractures and deformities causing pain, discomfort and high-care needs.
  - **Spastic co-contraction**
    - is the inappropriate activation of antagonistic muscles during voluntary activity.
    - It is *due to loss of reciprocal inhibition* during voluntary contraction. In spastic co-contraction, there are instead **mass contractions of both agonist and antagonistic muscles, resulting in loss of dexterity and slowed movements.**

- Characteristic Features of Spasticity
  - **Velocity dependence**
    - The increased tone of spasticity is velocity dependent, that is, the faster the stretch, the greater the muscle resistance
  - **‘Clasp-knife’ phenomenon**:
    - This is where the spastic limb initially resists movement and then suddenly gives way, rather like the resistance of a folding knife blade
    - On sustained movement, the inverse stretch reflex kicks in, relaxing the muscles with a ‘give away’ feel
    - In the later stage, as contractures set in, this is replaced by a non-elastic solid resistance
  - **Stroking effect**
    - Stroking the surface of the antagonistic muscle may reduce the tone in spasticity, though it does not affect contracture
  - **Distribution**
    - Spasticity has a differential distribution with antigravity muscles being more affected.

- Spasticity
- …..deregulation of the motor pathways (mainly the corticospinal, reticulospinal, and the vestibulospinal tracts) running from the cerebral cortex and brain stem to the spinal cord
- Instead, damage to tracts that interact with the corticospinal tract is thought to contribute to spasticity.
  - For example, damage along the reticulospinal tract decreases its inhibitory influence, resulting in increased muscle tone [15]
  - Loss of vestibulospinal tract excitation by the cortex is thought to cause decreased firing of the motor neurons, resulting in decreased extensor tone and thus a flexed posture


Extensors
Flexors


Extensors
Spastic and/or
Contracted
Flexors


Shoulder Adduction
and Internal Rotation
Elbow Flexion
Forearm
Pronation
Wrist Flexion
Finger Flexion
(Clenched fist with Thumb-
in-Palm Deformity


STROM telecom

- Annually, 15 million people worldwide have a stroke (15,000,000)
- Five million die (5,000,000)
- 5 million are left permanently disabled (5,000,000)
  - Complications:
    - Motor impairements (50–83%) (2,500,000 – 4,150,000)
    - Cognitive Impairements (50%) (2,500,000)
    - Language impairments (23–36%) (1,150,000 – 1,800,000)
    - poststroke seizures (10%) (500,000)
    - neuropathic pain (8%) (400,000)
    - Psychological disturbances (20%) (1,000,000)
- 33–42% of patients still require assistance for ADLs 3 – 6 years poststroke (1,650,000 – 2,100,000)
- 36% of patients remain disabled after five-years (1,800,000)

Brainin M1, Norrving B, Sunnerhagen KS, Goldstein LB, Cramer SC, Donnan GA, Duncan PW, Francisco G, Good D, Graham G, Kissela BM, Olver J, Ward A, Wissel J, Zorowitz R; International PSS Disability Study Group. **Poststroke chronic disease management: towards improved identification and interventions for poststroke spasticity-related complications.** *Int J Stroke. 2011 Feb;6(1):42-6.*

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- Stroke and its subsequent disabilities place a large burden on the family and community

- …2–4% of total health care costs globally
  - …lifetime cost estimated at **US$1 40 048** in the United States and **43 129** in Europe

- Even among those deemed ‘recovered’ from stroke based on a Barthel index score of >95, they still can have difficulties with
  - hand function
  - dependence in daily activities
  - impaired overall physical function
  - limitations of social participation

….all of which may impair quality of life

BARTHEL INDEX

		With Help	*Independent*
1.	Feeding (if food needs to be cut up = help)	5	10
2.	Moving from wheelchair to bed and return (includes sitting up in bed)	5-10	15
3.	Personal toilet (wash face, comb hair, shave, clean teeth)	0	5
4.	Getting on and off toilet (handling clothes, wipe, flush)	5	10
5.	Bathing self	0	5
6.	Walking on level surface (or if unable to walk, propel wheelchair) *score only if unable to walk	0*	5*
7.	Ascend and descend stairs	5	10
8.	Dressing (includes tying shoes, fastening fasteners)	5	10
9.	Controlling bowels	5	10
10.	Controlling bladder	5	10

- 460 post Stroke patients

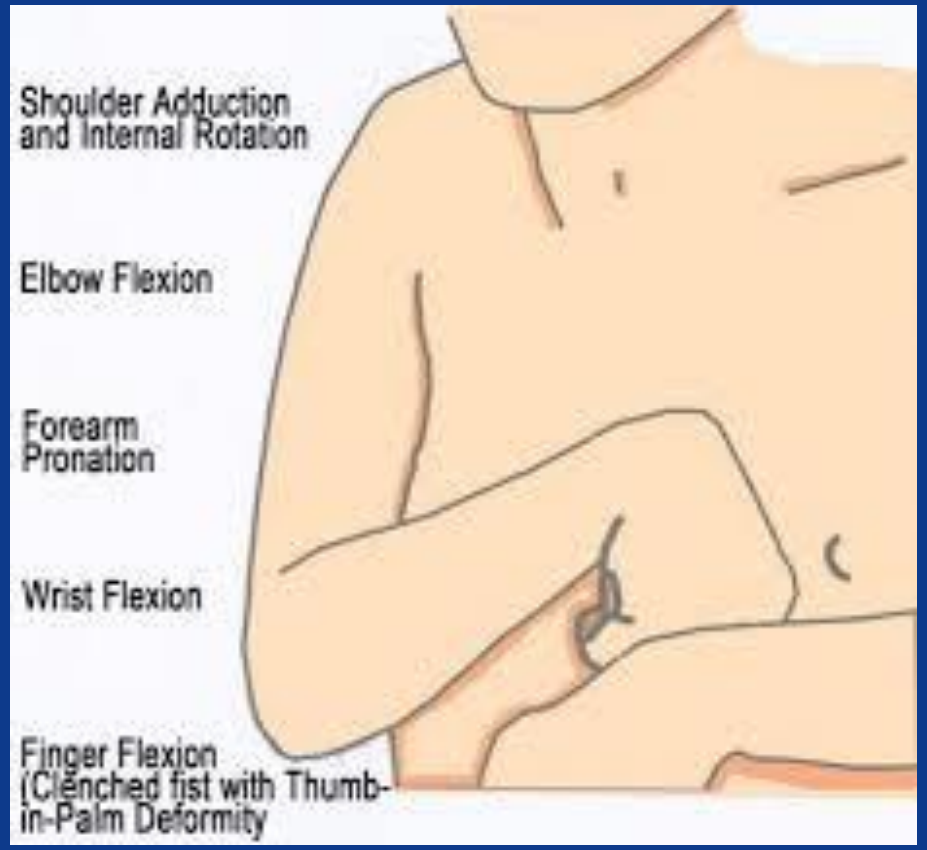
- **Spasticity**
  - …negative impact on the HRQoL (health-related quality of life) of stroke survivors
  - …statistically and clinically meaningful differences existing between stroke survivors with and without spasticity

- These results suggest an opportunity to improve HRQoL among stroke survivors with spasticity.

Gillard PJ, Sucharew H, Kleindorfer D, Belagaje S, Varon S, Alwell K, Moomaw CJ, Woo D, Khatri P, Flaherty ML, Adeoye O, Ferioli S, Kissela B. **The negative impact of spasticity on the health-related quality of life of stroke survivors: a longitudinal cohort study.** *Health Qual Life Outcomes. 2015 Sep 29;13:159.*

- Factors aggravating spasticity
  - Pressure ulcers
  - Ingrown toenails
  - Skin infections
  - Injuries
  - Constipation
  - Urinary tract infection
  - Urinary tract calculi
  - Deep vein thrombosis
  - Improper seating
  - Ill-fitting orthotics
  - Post-traumatic syringomyelia

Pattern
Adducted/internally rotated shoulder
Flexed elbow
Pronated forearm
Flexed wrist
Clenched fist
Thumb-in-palm deformity



Pattern	Muscles involved	
Adducted/internally rotated shoulder	Pectoralis major Teres major Latissimus dorsi Anterior deltoid Subscapularis	Teres major Latissimus dorsi Long head of triceps Posterior deltoid
Flexed elbow	Biceps Brachialis Brachioradialis	
Pronated forearm	Pronator teres Pronator quadratus	
Flexed wrist	Flexor carpi radialis Flexor carpi ulnaris Palmaris longus Extensor carpi ulnaris	
Clenched fist	Flexor digitorum sublimis and profundus	
Thumb-in-palm deformity	Flexor pollicis longus and brevis Adductor pollicis First dorsal interosseous	

Pattern	Muscles involved		Side-effects
Adducted/internally rotated shoulder	Pectoralis major Teres major Latissimus dorsi Anterior deltoid Subscapularis	Teres major Latissimus dorsi Long head of triceps Posterior deltoid	✓ Muscle contractures and pain ✓ Shoulder stiffness and painful passive range of motion ✓ Skin maceration, breakdown and malodor in the axilla ✓ Difficulties for dressing ✓ Limitation of the reaching-forward behaviour
Flexed elbow	Biceps Brachialis Brachioradialis		✓ Muscle contractures and pain ✓ Persistent elbow flexion during sitting, standing and walking ✓ Difficulties for transfer (no fulcrum), dressing and reaching objects ✓ Skin maceration, breakdown and malodor in the antecubital fossa ✓ Disfiguring appearance ✓ Stretch injury to the ulnar nerve (at the bend of the elbow) ✓ The nerve is vulnerable to repeated trauma and can be compressed in the cubital tunnel leading to intrinsic muscle atrophy in the hand and weakness of ulnar wrist and finger flexion
Pronated forearm	Pronator teres Pronator quadratus		✓ Muscle contractures and pain ✓ Difficulties to reach underhand to a target ✓ Limitations to turn the patient's hand palm side up for fingernail trimming (important for patients with fingers that are flexed into the palm secondary to a clenched fist deformity) ✓ Difficulties to feed (e.g., hold a spoon)
Flexed wrist	Flexor carpi radialis Flexor carpi ulnaris Palmaris longus Extensor carpi ulnaris		✓ Muscle contractures and pain ✓ Compression of the median nerve at wrist with carpal tunnel syndrome and hand pain ✓ Disfiguring appearance ✓ Awkward hand placement during reaching and impairs positioning of objects held ✓ Weakened grip strength
Clenched fist	Flexor digitorum sublimis and profundus		✓ Patients cannot perform the reach phase to grasp an object ✓ Fingernails digging into palmar skin with pain ✓ Nail bed infections ✓ Pain when somebody attempts to pry fingers open to gain palmar access ✓ Disfiguring appearance ✓ Skin maceration, breakdown and malodour in the palm ✓ Difficulties to wear gloves or hand splints ✓ Limitation for grasping, manipulation and release of objects ✓ Development of muscle, skin and joint contractures
Thumb-in-palm deformity	Flexor pollicis longus and brevis Adductor pollicis First dorsal interosseous		✓ Difficulties to wear gloves or hand splints ✓ Limitation of thumb extension and abduction that open up the web space before grasp ✓ Difficulties to execute grasp patterns (three-jaw chuck, lateral grasp and tip pinch)

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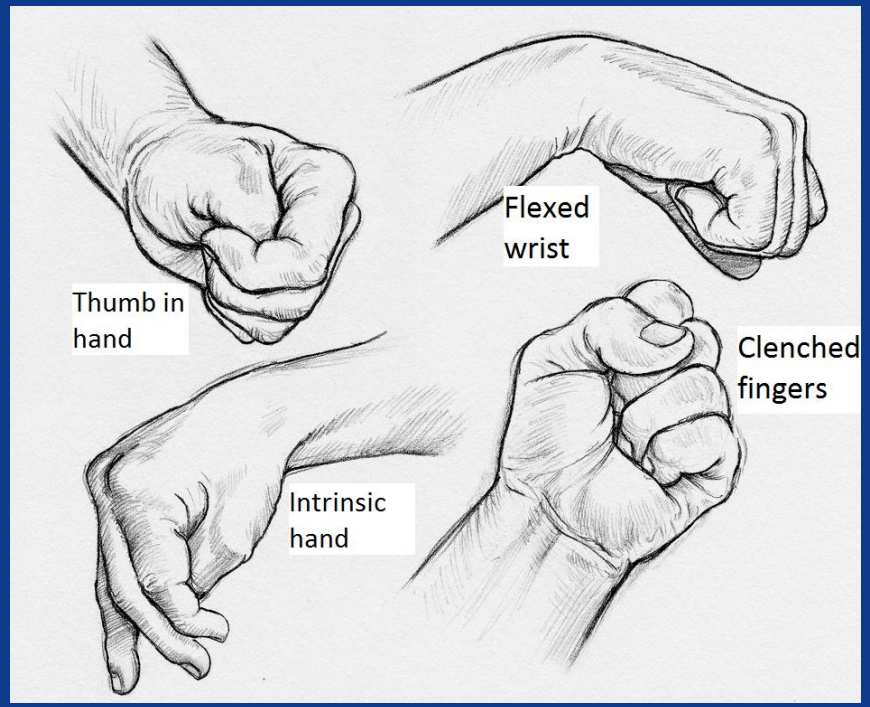
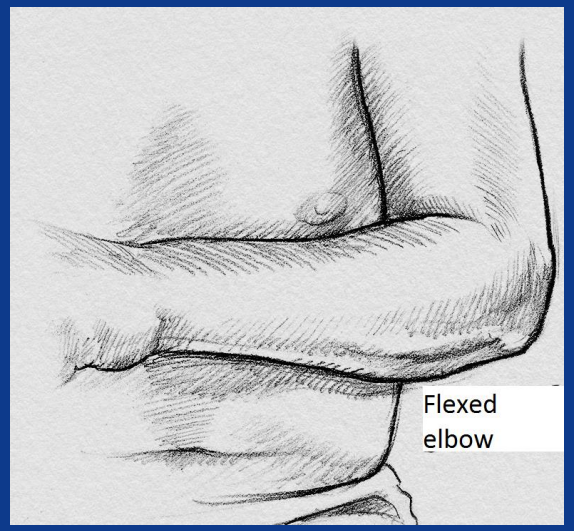
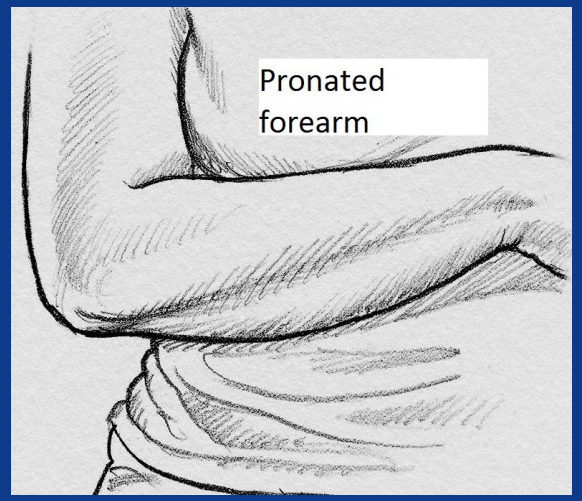
Assessing the patient







Spasticity

- Functional Upper Limb

- Non functional Upper Limb

- Muscle Contracture
- Joint Contracture
- Motor assessment
  - ✓Active muscles
  - ✓Paralyzed muscles
- Sensory assessment
- Functional assessment
  - ✓Functional Tests
    - AHA (Assisting Hand Assessment)
    - The pick-up and release test
    - The box and Block test
    - Bimanual Activities
  - ✓Questionnaires

- General Assessment
  - ✓Other neurologic impairments
    - Athetosis
    - Chorea
    - Parkinsons
  - ✓Age
  - ✓Motivation and environment
  - ✓X-rays
  - ✓EMG
    - ✓ muscles can be utilized for tendon transfer only if they are capable of relaxation at rest or during the antagonist movement (phasic control).

Trophic changes, such as reflex sympathetic dystrophy and vaso-motor changes, are frequently associated – contraindication for surgery

- Better clinical outcomes have been noted when postacute stroke patients receive **coordinated, multidisciplinary intervention** involving
  - Physician
  - Nurse
  - Physical therapist
  - Occupational therapist
  - Kinesiotherapist
  - Speech and language pathologist
  - Psychologist
  - Recreational therapist
  - Family/caregivers

Individualized treatment

Spasticity

Modified Tardieu Scale

X: Quality of movement mobilization

0	No resistance throughout the course of the passive movement
1	Slight resistance throughout the course of passive movement, no clear catch at a precise angle
2	Clear catch at a precise angle, interrupting the passive movement, followed by release
3	Fatigable clonus with less than 10 seconds when maintaining the pressure and appearing at the precise angle
4	Unfatigable clonus with more than 10 seconds when maintaining the pressure and appearing at a precise angle
5	Joint is fixed

V: Measurements take place at three different velocities

V1	As slow as possible
V2	Speed of limb segment falling under gravity
V3	As fast as possible
Y:	Angle of catching (muscle reaction)

Spasticity

Modified Ashworth scale

X: Quality of movement mobilization

0	**No increase in muscle tone**
1	Slight increase in muscle tone
1+	Slight increase in muscle resistance throughout the range
2	Moderate increase in muscle tone throughout the range of motion; passive movement is easy
3	Marked increase in muscle tone throughout the range of motion; passive movement is difficult
4	Marked increase in muscle tone; affected part is rigid

Spasticity

House's Functional Classification System

Class	*Designation*	*Activity level*
0	Does not use	Does not use
1	Poor passive assist	Uses as stabilizing weight only
2	Fair passive assist	Can hold onto object placed in hand
3	Good passive assist	Can hold onto object and stabilize it for use by other hand
4	Poor active assist	Can actively grasp object and hold it weakly
5	Fair active assist	Can actively grasp object and stabilize it well
6	Good active assist	Can actively grasp object and then manipulate it against other hand
7	Spontaneous use	Can perform bimanual activities easily and occasionally uses the hand spontaneously
8	Spontaneous use	Uses hand completely independently without reference to the other hand

Stiffness after CVA

- Neurologic contractures
  - Spasticity
  - Spastic Dystonia
  - Spastic co-contracture
- Muscle contracture
- Joint Contracture

- Characteristic Features of Spasticity
  - **Velocity dependence**
    - The increased tone of spasticity is velocity dependent, that is, the faster the stretch, the greater the muscle resistance
  - **‘Clasp-knife’ phenomenon**:
    - This is where the spastic limb initially resists movement and then suddenly gives way, rather like the resistance of a folding knife blade
    - On sustained movement, the inverse stretch reflex kicks in, relaxing the muscles with a ‘give away’ feel
    - In the later stage, as contractures set in, this is replaced by a non-elastic solid resistance
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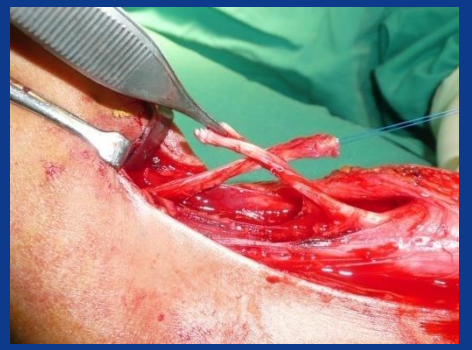
    - On sustained movement, the inverse stretch reflex kicks in, relaxing the muscles with a 'give away' feel
    - In the later stage, as contractures set in, this is replaced by a non-elastic solid resistance
  - **Stroking effect**
    - Stroking the surface of the antagonistic muscle may reduce the tone in spasticity, though it does not affect contracture
  - **Distribution**
    - Spasticity has a differential distribution with antigravity muscles being more affected.

Spasticity + muscle contracture + joint contracture

Courtesy to Mme Caroline Leclercq, Institut De La Main, Paris

Muscle lengthening (biceps + BR)



Remaining joint contracture

Courtesy to Mme Caroline Leclercq, Institut De La Main, Paris

Nonoperative Treatments

- Medication
- Physical Therapy/Occupational Therapy
- Chemodenervation
  - Botulinum Toxin
  - Phenol

Operative Treatments

Drugs	Action	Major Adverse Events
Baclofen	Reduces release of excitatory neurotransmitters and Substance P in the spinal cord Decreases post synaptic effect of excitatory neurotransmitters	Sedation Weakness Seizures Hallucinations
Tizanidine	Reduces release of excitatory neurotransmitters and Substance P in the spinal cord Decreases neuronal firing in locus coeruleus	Sedation Dry mouth Dizziness
Benzodiazepines	Enhances presynaptic and postsynaptic inhibition in the spinal cord through GABA pathways	Sedation Fatigue Habituation
Dantrolene	Inhibits release of calcium from muscle sarcoplasmic reticulum	Weakness Hepatotoxicity
Clonidine	Similar to tizanidine	Orthostatic hypotension
Phenothiazines	Reduces gamma motor excitability	Extrapyramidal side effects Sedation

Physical Therapy/Occupational Therapy

- Physical Treatments
  - ROM
  - Stretching
  - Serial casting
  - Dynamic splinting
  - Constraint induced therapy
- Therapeutic exercise
  - Strengthening
- Modalities
  - Electrical stimulation
  - Thermal modalities
- Combination

Chemodenervation – Botulinum toxin

- …weakening and relaxation of muscle overactivity
- …biomechanical change in the muscle's function makes it amenable to stretching and lengthening
- …weakening allows an opportunity to strengthening of antagonist muscles, and thereby it is possible to restore some of the balance between the two

Chemodenervation – Botulinum toxin

- …improvements in tone 4 weeks after a single injection session of 500 U or 1000 U of abobotulinum toxin A
- …these improvements were noted as early as week 1 and persisted for at least 12 weeks
- …improvement in active range of motion in all movements assessed in the upper limb (elbow, wrist, or finger extension) in the abobotulinum toxin A 1000 U group, and a reduction of spasticity and spastic dystonia (Tardieu Scale).
- The results of this study might provide a rationale for the use of abobotulinum toxin A injected into co-contracting antagonists to improve active motion and not only to reduce resistance to passive movement.

Gracies JM, Brashear A, Jech R, McAllister P, Banach M, Valkovic P, Walker H, Marciniak C, Deltombe T, Skoromets A, Khatkova S, Edgley S, Gul F, Catus F, De Fer BB, Vilain C, Picaut P; International Abobotulinum toxin A Adult Upper Limb Spasticity Study Group. **Safety and efficacy of abobotulinumtoxinA for hemiparesis in adults with upper limb spasticity after stroke or traumatic brain injury: a double-blind randomised controlled trial.** *Lancet Neurol. 2015 Oct;14(10):992-1001.*

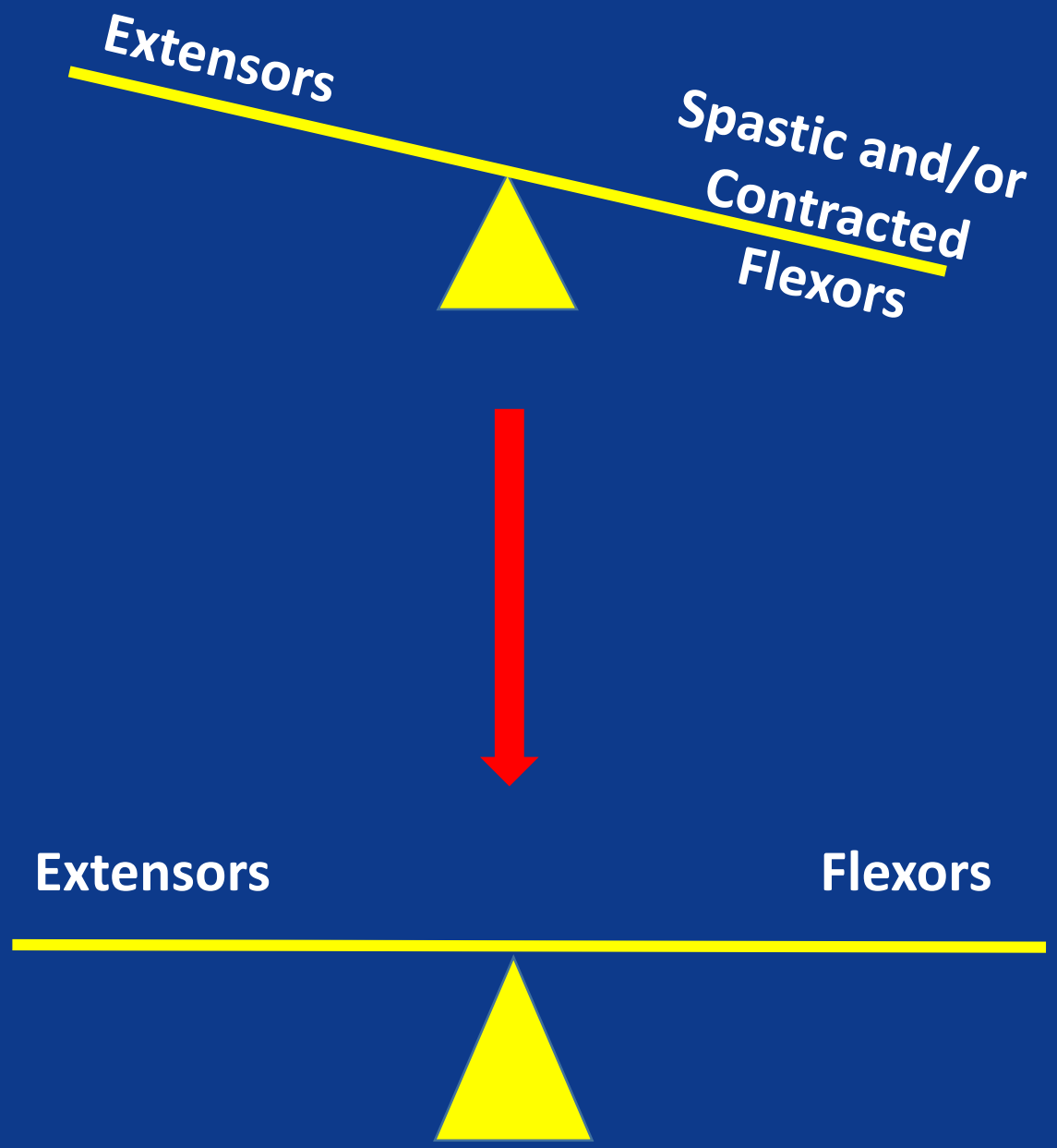
Chemodenervation – Phenol

- …perineural injection of motor nerves using 3% to 6% phenol in aqueous solution
- …LA effect followed by blockade 1 hour later
- …leaves the nerve with 25% less function than before
- …lasts for 4-6 months
- …as an alternative to BOTOX, or surgery for focal problems
- …disadvantage
  - …more time to perform
  - …can cause dysthesia (if in proximity with sensory nerve fibres)

Surgery for Spasticity

1. Decrease Muscle Forces
2. Eliminate Muscle Forces
3. Redirect Muscle Forces
4. Mobilize Stiff Joints
5. Restore Balance to joints
6. Stabilize Joints

1. Restore Volitional Control to Muscles
2. Increase Muscle Force Generation


Extensors
Spastic and/or
Contracted
Flexors
Extensors
Flexors

Surgery for Spasticity		
Target Organ	**Procedure**	
Brain	Stereotactic Neurosurgery Cerebellar stimulation	
Spinal Cord	Posterior rhizotomy	
Peripheral Nerve	Neurectomy	
Muscle or Tendon	Lengthening Release Transfer	Tenotomy Tenodesis
Joint	Fusion	

Surgical Goals

1. Improved Function
    - Active function
    - Passive function
2. Pain relief
3. Decreased reliance on systemic medication
4. Permanent solution rather than temporizing treatment
5. Improved Cosmesis
6. Improved Hygiene

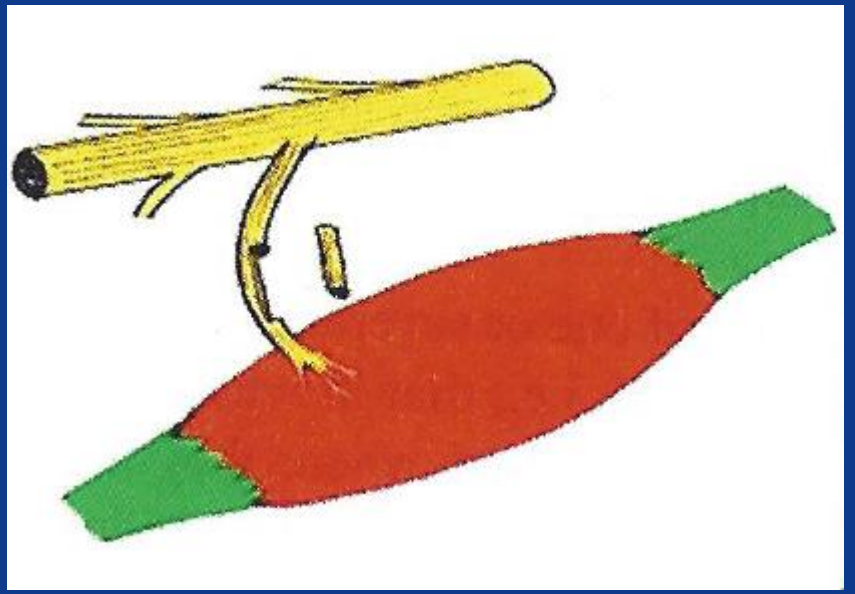
Timing of Surgery

Early Surgery	Later Surgery
Advantages: • Supple joints • Shorter duration of disability	Advantages: • Natural History of recovery more clearly known • Greater healing from initial injury
Disadvantages: • Neurologic condition may still be dynamic and unpredictable • Medical morbidities and initial injury are relatively recent	Disadvantages: • Stiffer joints • Longer disability

Peripheral Nerve	Neurectomy
Muscle or Tendon	Lengthening Release Transfer Tenotomy Tenodesis
Joint	Fusion

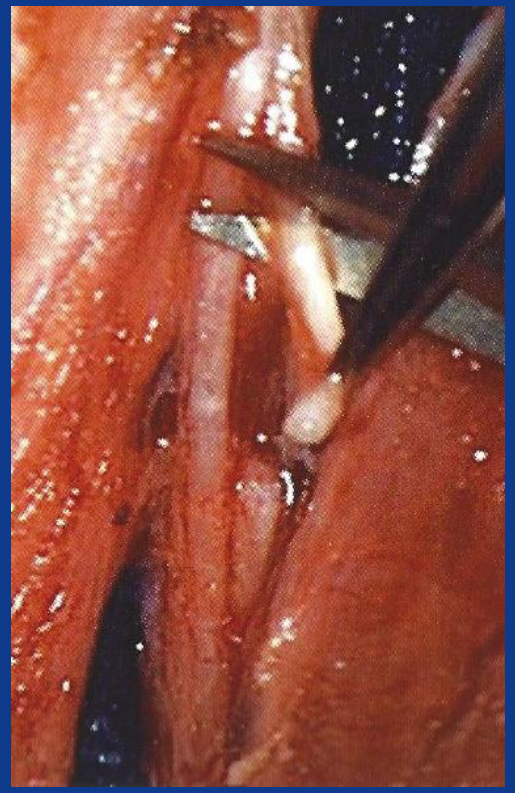
Peripheral Nerve	Neurectomy
Muscle or Tendon	Lengthening Release Transfer Tenotomy Tenodesis
Joint	Fusion

- Neurectomy
  - Partial sectioning of one or several motor branches of the nerves innervating the muscles to be targeted
  - Motor branches must be accessed where they are already clearly isolated from the nerve trunk or they must be dissected and identified as motor fascicles within the nerve trunk proximal to the formation of an identifiable branch



- No scientific data defining the extent of partial section (usually 75%)

- Upper limb neurectomies
  - 71 patients
    - Brachial plexus (3)
    - Musculocutaneous nerve (15)
    - Median/ulnar nerve (53)
- Results
  - Significant decrease in spasticity
  - Resting position, range of motion, active joint amplitude, and antagonist motor strength were improved
  - Hand function
    - 2/3 were operated for comfort and cosmetic gain
      - Significant improvement
    - 1/3 operated for functional improvement
      - 72.7% pressure paper function
      - 81.8% active hand opening
  - Pain
    - Preop: 8.2, postop: 1.3



Musculocutaneous neurectomy

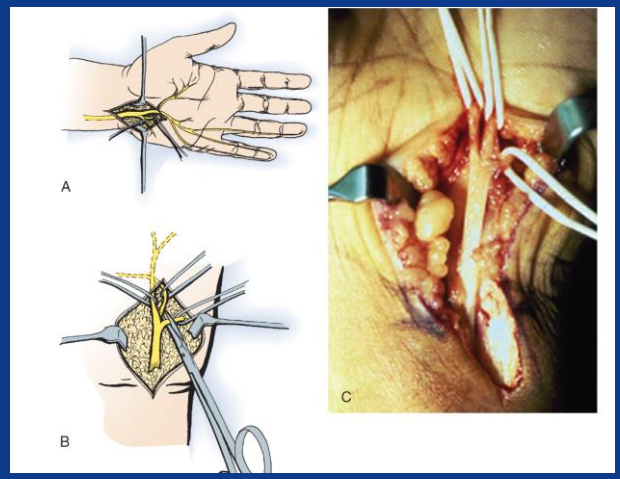
- 29 ptns / 30 neurectomies - 28/29 improved - No recurrence

Garland DE, Thompson R, Waters RL. Musculocutaneous neurectomy for spastic elbow flexion in non-functional upper extremities in adults. J Bone Joint Surg Am. 1980 Jan;62(1):108-12.

- If no contracture

Roper BA. The orthopedic management of the stroke patient. Clin Orthop Relat Res. 1987 Jun;(219):78-86.

neurectomy of the motor branch of the ulnar nerve



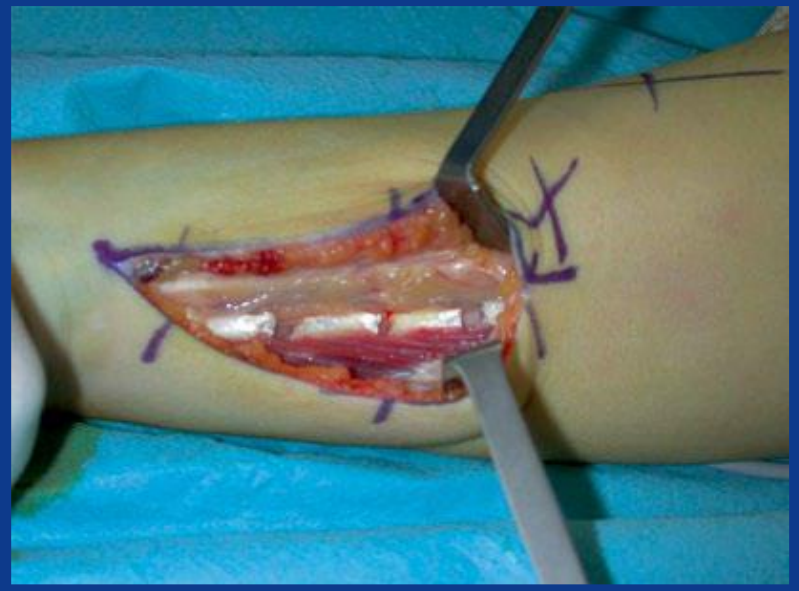
- Intrinsic Spasticity

Keenan MA Management of the spastic upper extremity in the neurologically impaired adult. ClinOrthop Relat Res. 1988 Aug;(233):116-25

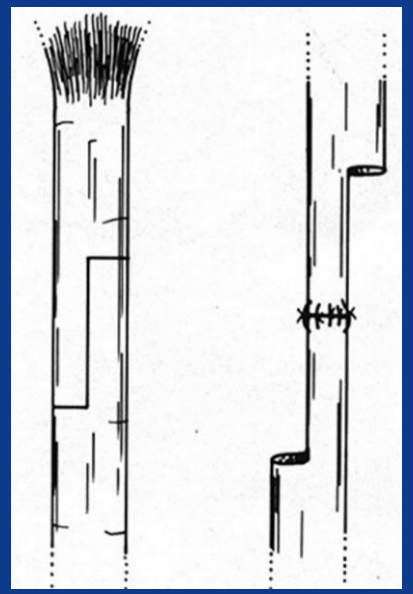
Peripheral Nerve	Neurectomy
Muscle or Tendon	**Lengthening** Release Transfer Tenotomy Tenodesis
Joint	Fusion

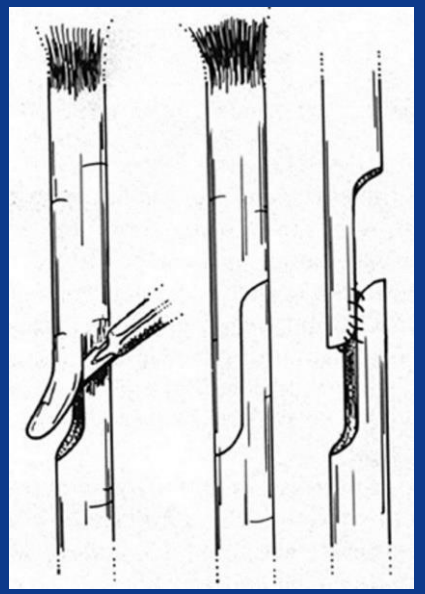
Tendon Lengthenings

- **Fractional lengthening**



- **Z-lengthenings**





- Shoulder Fractional Lengthenings
  - 34 hemiparetic patients – all had lengthenings of pec major, lat dorsi and teres major, 4 also had long head of triceps fractional lengthening
  - …significant improvement in AROM + pain

Namdari S, Alosh H, Baldwin K, Mehta S, Keenan MA. Outcomes of tendon fractional lengthenings to improve shoulder function in patients with spastic hemiparesis. J Shoulder Elbow Surg. 2012 May;21(5):691-8

- Fractional lengthening of the brachialis tendon
    - + Z-lengthening of the biceps tendon + Proximal release of the BR

Keenan MA Management of the spastic upper extremity in the neurologically impaired adult. ClinOrthop Relat Res. 1988 Aug;(233):116-25

- Fractional lengthening of the finger flexors.
  - 27 patients/22 functional - 20/22 increased function - 2/22 decreased function – lost flexion

Keenan MA, Abrams RA, Garland DE, Waters RL. Results of fractional lengthening of the finger flexors in adults with upper extremity spasticity. J Hand Surg Am. 1987 Jul;12(4):575-81.

- Z-lengthening of the biceps tendon
  - + Fractional lengthening of the brachialis tendon + Proximal release of the BR,

- FCR, FCU: Z-lengthening
  - + FDS, FDP, FPL: fractional lengthening + PL: devided,

- …FPL tendon lengthening
  - +/- IPJ fusion)

Keenan MA Management of the spastic upper extremity in the neurologically impaired adult. ClinOrthop Relat Res. 1988 Aug;(233):116-25.

Peripheral Nerve	Neurectomy
Muscle or Tendon	Lengthening **Release** Transfer Tenotomy Tenodesis
Joint	Fusion

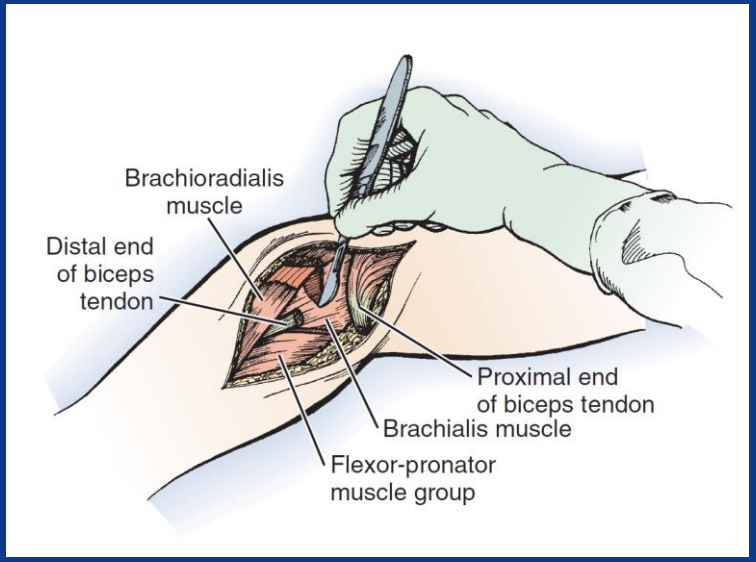
- Proximal release of the BR,
  - Z-lengthening of the biceps tendon, Fractional lengthening of the brachialis tendon

Keenan MA Management of the spastic upper extremity in the neurologically impaired adult. ClinOrthop Relat Res. 1988 Aug;(233):116-25.

- Flexor slide (elevation of all the forearm muscles from the bones and interosseous membrane)
  - Gives floppy hand rather than the fairly easily recognized deformity

Roper BA. The orthopedic management of the stroke patient. Clin Orthop Relat Res. 1987 Jun;(219):78-86

- release of BR, Biceps, brachialis
- …longitudinal incision on the lateral side of the elbow



Keenan MA Management of the spastic upper extremity in the neurologically impaired adult. ClinOrthop Relat Res. 1988 Aug;(233):116-25

- release of thenar muscles +/- 1st dorsal interosseous
  - (Proximal myotomy)
  - secondary to spasticity of Median and ulnar innervated thenar muscles

Keenan MA Management of the spastic upper extremity in the neurologically impaired adult. ClinOrthop Relat Res. 1988 Aug;(233):116-25

Peripheral Nerve	Neurectomy
Muscle or Tendon	Lengthening Release **Transfer** Tenotomy Tenodesis
Joint	Release Fusion

Superficialis to profundus : STP

Braun

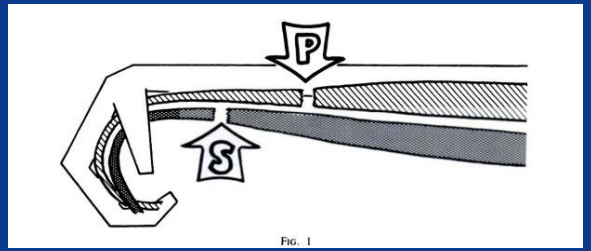
-distal section FDS

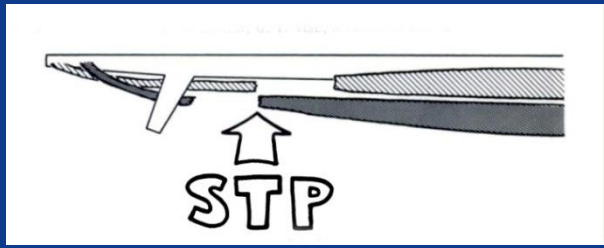
-proximal section FDP

- slide and terminal suture

➔ limited active flexion

Optimal for non functional hands





Courtesy to Mme Caroline Leclercq, Institut De La Main, Paris

Superficialis to profundus tendon transfer (STP)

……may be considered when the goal is to improve passive function only

Keenan MA Management of the spastic upper extremity in the neurologically impaired adult. ClinOrthop Relat Res. 1988 Aug;(233):116-25.

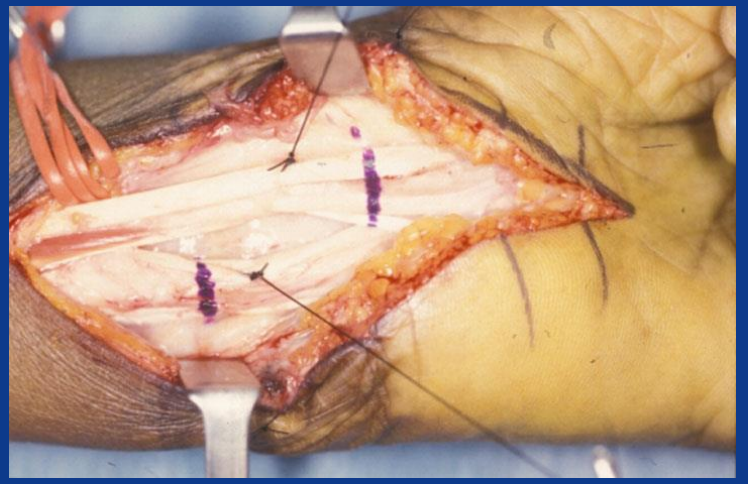
(+ release of PL and lengthening of wrist flexors and FPL)

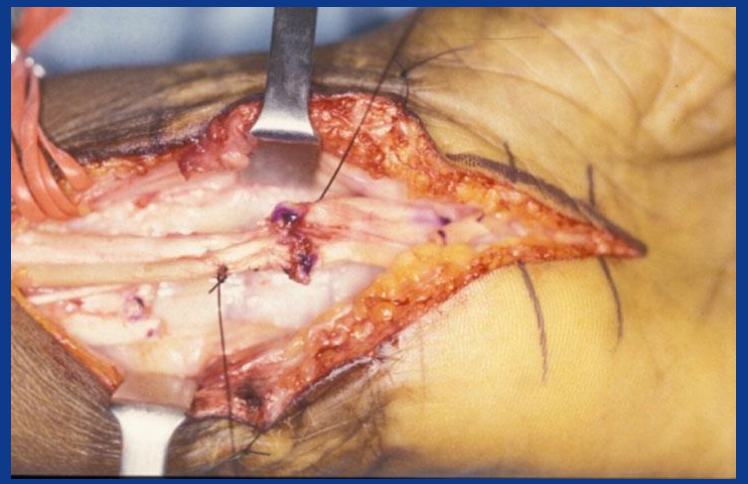
Heijnen IC1, Franken RJ, Bevaart BJ, Meijer JW. Long-term outcome of superficialis-to-profundus tendon transfer in patients with clenched fist due to spastic hemiplegia. Disabil Rehabil. 2008;30(9):675-8.

6 patients - Still fully passive motion - +/- FCR, FCU and FPL lengthening, CTD

Keenan MA, Korchek JI, Botte MJ, Smith CW, Garland DE. Results of transfer of the flexor digitorum superficialis tendons to the flexor digitorum profundus tendons in adults with acquired spasticity of the hand. J Bone Joint Surg Am. 1987 Oct;69(8):1127-32.

31 patients - 34 hands - Motor branch of UN neurectomy in 25/34





Courtesy to Mme Caroline Leclercq, Institut De La Main, Paris

Peripheral Nerve	Neurectomy
Muscle or Tendon	Lengthening Release Transfer **Tenotomy** Tenodesis
Joint	Fusion

Shoulder Tenotomies

pectoralis major, latissimus dorsi, teres major and subscapularis

- in nonfunctional extremity all four (pectoralis major, latissimus dorsi, teres major and subscapularis) should be released

- …36 hemiplegic patients
- ….preop: pain, difficulty with dressing, skin care or hygiene
- ….postop: improved pain relief, passive ROM, hygiene, skin care and caregiver-assisted dressing.

Namdari S, Alosh H, Baldwin K, Mehta S, Keenan MA. **Shoulder tenotomies to improve passive motion and relieve pain in patients with spastic hemiplegia after upper motor neuron injury.** *J Shoulder Elbow Surg. 2011 Jul;20(5):802-6*

- Division of brachialis
  - +/- lengthening of the biceps
- if spasticity + flexion contracture

Roper BA. The orthopedic management of the stroke patient. Clin Orthop Relat Res. 1987 Jun;(219):78-8

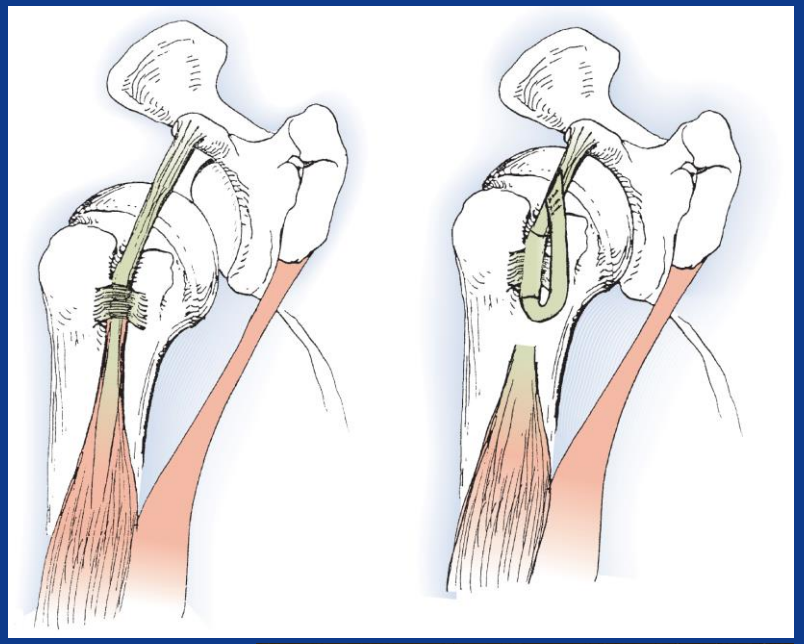
- Division of Palmaris Longus
  - +FCR, FCU: Z-lengthening, FDS, FDP, FPL: fractional lengthening (Wrist and Finger Flexor Lengthening)

Keenan MA Management of the spastic upper extremity in the neurologically impaired adult. ClinOrthop Relat Res. 1988 Aug;(233):116-25

Peripheral Nerve	Neurectomy
Muscle or Tendon	Lengthening Release Transfer Tenotomy **Tenodesis**
Joint	Fusion

Biceps Suspension Procedure

- pectoralis major tenotomy (if needed) – release of the insertion of lattisimus dorsi and teres major

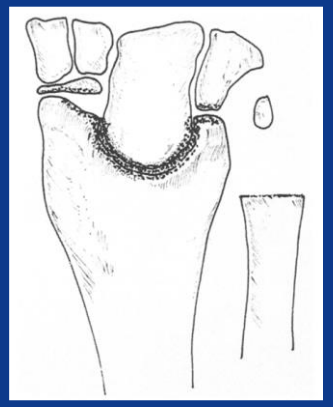


- …decrease in pain 11/11
- …shoulder passive ROM was increased in all planes

Namdari S, Keenan MA Outcomes of the biceps suspension procedure for painful inferior glenohumeral subluxation in hemiplegic patients. J Bone Joint Surg Am. 2010 Nov 3;92(15):2589-97

Peripheral Nerve	Neurectomy
Muscle or Tendon	Lengthening Release Transfer Tenotomy Tenodesis
Joint	**Fusion**

Wrist fusion



- The mean radiographic flexion deformity significantly improved from 67° pre-operatively to 4° of dorsal angulation post-operatively
- +/- tenotomy of wrist flexors, +/- PRC
- Arthrodesis at neutral, or as close to neutral
- + superficialis-to-profundus transfer in non-functional hands with clenched fists

Neuhaus V, Kadzielski JJ, Mudgal CS. **The role of arthrodesis of the wrist in spastic disorders.** *J Hand Surg Eur Vol. 2015 Jun;40(5):512-7*

Louis DS, Hankin FM, Bowers WH. **Capitate-radius arthrodesis: an alternative method of radiocarpal arthrodesis.** *J Hand Surg Am. 1984 May;9(3):365-9.*

- Metacarpal head resection
  - fingers-in-palm deformity in longstanding neurological injury

Das AK, Talwalkar SC, Murali SR. Metacarpal head resection for treatment of the fingers-in-palm deformity in longstanding neurological injury. J Hand Surg Eur Vol. 2015 Mar;40(3):319-20

- Not many spastic patients are candidates for surgery of their upper limb, because of the many other neurological problems frequently associated

- Stiffness
- CVA
- CVA to stiffness
- Treatment
- **Take Home message**

- 1,197 patients with acute stroke.
- The time course of functional recovery was strongly related to initial stroke severity.
  - Best ADL function
    - Mild Strokes - within 8.5 weeks (CI 8 to 9)
    - Moderate Strokes - within 13 weeks (CI 12 to 14)
    - Severe Strokes - within 17 weeks (CI 15 to 19)
    - Very severe Strokes - within 20 weeks (CI 16 to 24)
- After these time-points, no significant changes occurred.

Jørgensen HS, Nakayama H, Raaschou HO, Vive-Larsen J, Støier M, Olsen TS. **Outcome and time course of recovery in stroke. Part II: Time course of recovery. The Copenhagen Stroke Study.** *Arch Phys Med Rehabil. 1995 May;76(5):406-12.*

- 1,197 patients with acute stroke.
- However, a **valid prognosis** of functional outcome can be made much earlier.
  - Best ADL function in 80% of the patients
    - mild strokes - within 3 weeks (CI 2.6 to 3.4)
    - Moderate Strokes - within 7 weeks (CI 6 to 8)
    - Severe and Very Severe Strokes - within 11.5 weeks (CI 10 to 13)
- A **reliable prognosis** can in all stroke patients be made within **12 weeks from stroke onset**. Even in patients with severe and very severe strokes, neurological and functional recovery should not be expected after the first 5 months

Jørgensen HS, Nakayama H, Raaschou HO, Vive-Larsen J, Støier M, Olsen TS. **Outcome and time course of recovery in stroke. Part II: Time course of recovery. The Copenhagen Stroke Study.** *Arch Phys Med Rehabil. 1995 May;76(5):406-12.*

Risk factors significantly predictive of permanent poststroke spasticity	
Risk factor	**P value**
Any paresis in affected limb	0.001
MAS ≥2 in ≥1 joint within median 6 weeks poststroke	0.01
>2 joints affected by increased muscle tone	0.002
Hemispasticity within median 6 weeks poststroke	0.01
Lower Barthel Index score at baseline	0.002
More severe paresis at median 16 weeks poststroke	0.02

Sunnerhagen KS. **Predictors of Spasticity After Stroke**. *Curr Phys Med Rehabil Rep. 2016;4:182-185*.

- …no benefits of additional physiotherapy using the current British approach for patients with initial severe arm impairment

- Uncontrolled spasticity can lead to permanent contracture in the muscles and soft tissues

- …contracture can arise as a result of joint, muscle, or soft tissue limitations

- ...prolonged immobilization of a joint, in a shortened position, results in contracture formation

58 y.o. , stroke
Severe spasticity

-pain
-difficulty in nursing

Courtesy to Mme Caroline Leclercq, Institut De La Main, Paris

- Is there a reason why we should wait for the contractures to develop?

References

- Pandyan AD, Cameron M, Powell J, Stott DJ, Granat MH. **Contractures in the post-stroke wrist: a pilot study of its time course of development and its association with upper limb recovery**. *Clin Rehabil. 2003 Feb;17(1):88-95*.
- Brainin M1, Norrving B, Sunnerhagen KS, Goldstein LB, Cramer SC, Donnan GA, Duncan PW, Francisco G, Good D, Graham G, Kissela BM, Olver J, Ward A, Wissel J, Zorowitz R; International PSS Disability Study Group. **Poststroke chronic disease management: towards improved identification and interventions for poststroke spasticity-related complications.** *Int J Stroke. 2011 Feb;6(1):42-6*.
- Parry RH, Lincoln NB, Vass CD. **Effect of severity of arm impairment on response to additional physiotherapy early after stroke**. *Clin Rehabil. 1999 Jun;13(3):187-98.*
- Sunnerhagen KS. **Predictors of Spasticity After Stroke**. *Curr Phys Med Rehabil Rep. 2016;4:182-185*.
- Jørgensen HS, Nakayama H, Raaschou HO, Vive-Larsen J, Støier M, Olsen TS. **Outcome and time course of recovery in stroke. Part II: Time course of recovery. The Copenhagen Stroke Study.** *Arch Phys Med Rehabil. 1995 May;76(5):406-12.*
- Neurological contractures: the spastic upper limb. C Leclercq - Disorders of the Hand, 2015 - Springer
- Das AK, Talwalkar SC, Murali SR. Metacarpal head resection for treatment of the fingers-in-palm deformity in longstanding neurological injury. J Hand Surg Eur Vol. 2015 Mar;40(3):319-20
- Neuhaus V, Kadzielski JJ, Mudgal CS. **The role of arthrodesis of the wrist in spastic disorders.** *J Hand Surg Eur Vol. 2015 Jun;40(5):512-7*
- Louis DS, Hankin FM, Bowers WH. **Capitate-radius arthrodesis: an alternative method of radiocarpal arthrodesis.** *J Hand Surg Am. 1984 May;9(3):365-9.*
- Namdari S, Keenan MA Outcomes of the biceps suspension procedure for painful inferior glenohumeral subluxation in hemiplegic patients. J Bone Joint Surg Am. 2010 Nov 3;92(15):2589-97
- Roper BA. The orthopedic management of the stroke patient. Clin Orthop Relat Res. 1987 Jun;(219):78-8

References

- Namdari S, Baldwin K, Horneff JG, Keenan MA. **Orthopedic evaluation and surgical treatment of the spastic shoulder.** *Orthop Clin North Am. 2013 Oct;44(4):605-14.*
- Kheder A, Nair KP. **Spasticity: pathophysiology, evaluation and management**. *Pract Neurol. 2012 Oct;12(5):289-98.*
- Thibaut A, Chatelle C, Ziegler E, Bruno MA, Laureys S, Gosseries O. **Spasticity after stroke: physiology, assessment and treatment.** *Brain Inj. 2013;27(10):1093-105.*
- Gillard PJ, Sucharew H, Kleindorfer D, Belagaje S, Varon S, Alwell K, Moomaw CJ, Woo D, Khatri P, Flaherty ML, Adeoye O, Ferioli S, Kissela B. **The negative impact of spasticity on the health-related quality of life of stroke survivors: a longitudinal cohort study.** *Health Qual Life Outcomes. 2015 Sep 29;13:159.*
- Lance J. **Spasticity: disorders motor control.** *In: Feldman RG, Young RP, Koella WP editors. Symposium synopsis. Miami, FL: Year Book Medical Publishers*; 1980
- Mukherjee A, Chakravarty A. **Spasticity mechanisms - for the clinician**. *Front Neurol. 2010 Dec 17;1:149*
- Robert Teasell, Norhayati Hussein, Ricardo Viana, Mona Madady, Sarah Donaldson, Andrew McClure, Marina Richardson, **Stroke Rehabilitation Clinician Handbook**, 2014
- Sacco RL, Kasner SE, Broderick JP, Caplan LR, Connors JJ, Culebras A, Elkind MS, George MG, Hamdan AD, Higashida RT, Hoh BL, Janis LS, Kase CS, Kleindorfer DO, Lee JM, Moseley ME, Peterson ED, Turan TN, Valderrama AL, Vinters HV; American Heart Association Stroke Council, Council on Cardiovascular Surgery and Anesthesia; Council on Cardiovascular Radiology and Intervention; Council on Cardiovascular and Stroke Nursing; Council on Epidemiology and Prevention; Council on Peripheral Vascular Disease; Council on Nutrition, Physical Activity and Metabolism. **An updated definition of stroke for the 21st century: a statement for healthcare professionals from the American Heart Association/American Stroke Association**. *Stroke. 2013 Jul;44(7):2064-89.*
- Bong MR, Di Cesare PE. Stiffness after total knee arthroplasty. J Am Acad Orthop Surg. 2004 May-Jun;12(3):164-71.
- Baumgart E. **Stiffness--an unknown world of mechanical science?** *Injury. 2000 May;31 Suppl 2:S-B14-23*

References

- Keenan MA Management of the spastic upper extremity in the neurologically impaired adult. ClinOrthop Relat Res. 1988 Aug;(233):116-25
- Namdari S, Alosh H, Baldwin K, Mehta S, Keenan MA. **Shoulder tenotomies to improve passive motion and relieve pain in patients with spastic hemiplegia after upper motor neuron injury.** *J Shoulder Elbow Surg. 2011 Jul;20(5):802-6*
- Heijnen IC1, Franken RJ, Bevaart BJ, Meijer JW. Long-term outcome of superficialis-to-profundus tendon transfer in patients with clenched fist due to spastic hemiplegia. Disabil Rehabil. 2008;30(9):675-8.
- Keenan MA, Korchek JI, Botte MJ, Smith CW, Garland DE. Results of transfer of the flexor digitorum superficialis tendons to the flexor digitorum profundus tendons in adults with acquired spasticity of the hand. J Bone Joint Surg Am. 1987 Oct;69(8):1127-32.
- Keenan MA, Abrams RA, Garland DE, Waters RL. Results of fractional lengthening of the finger flexors in adults with upper extremity spasticity. J Hand Surg Am. 1987 Jul;12(4):575-81.
- Namdari S, Alosh H, Baldwin K, Mehta S, Keenan MA. Outcomes of tendon fractional lengthenings to improve shoulder function in patients with spastic hemiparesis. J Shoulder Elbow Surg. 2012 May;21(5):691-8
- Garland DE, Thompson R, Waters RL. Musculocutaneous neurectomy for spastic elbow flexion in non-functional upper extremities in adults. J Bone Joint Surg Am. 1980 Jan;62(1):108-12.
- M.Sindou et al., Neurosurgery for Spasticity, DOI 10.1007/978-3-7091-2_8, Springer-Verlag Wien 2014
- Allison Brashear, Elie Elovic, Spasticity: Diagnosis and Management. *Demo Medical Publishing, 2011*
- Gracies JM, Brashear A, Jech R, McAllister P, Banach M, Valkovic P, Walker H, Marciniak C, Deltombe T, Skoromets A, Khatkova S, Edgley S, Gul F, Catus F, De Fer BB, Vilain C, Picaut P; International Abobotulinum toxin A Adult Upper Limb Spasticity Study Group. **Safety and efficacy of abobotulinumtoxinA for hemiparesis in adults with upper limb spasticity after stroke or traumatic brain injury: a double-blind randomised controlled trial.** *Lancet Neurol. 2015 Oct;14(10):992-1001.*
- Gelber, DA and Jozefczyk, PB. **Therapeutics in the Management of Spasticity.** *Neurorehabilitation and Neural Repair 1999;13:5-14*


Thank you