Clinical Review

Journal of the Royal Society of Medicine Open;
15(8) 1–6
DOI: 10.1177/20542704241278544

Surgical reconstruction for spasticity and contracture: An underutilised rehabilitative strategy of adult stroke

Marvin Man Ting Chung[1] and **Wing Yuk Ip**[1]
[1]Department of Orthopaedics and Traumatology, University of Hong Kong, Pok Fu Lam, Hong Kong
Corresponding author: Marvin Man Ting Chung, Department of Orthopaedics and Traumatology, University of Hong Kong, 5/F Professorial Block, Queen Mary Hospital, 102 Pokfulam Road, Pok Fu Lam, Hong Kong. Email: marvinchung@ortho.hku.hk

Summary
Post-stroke spasticity and contracture remain prevalent and pose significant challenges in stroke rehabilitation. While non-surgical management is the mainstay, surgical reconstruction offers a valuable adjunct when conservative measures are exhausted. This clinical review article provides an overview of surgical reconstruction for limb spasticity and contracture following adult stroke, encompassing the rationale and specifics of these interventions. It highlights the underutilization of surgical reconstruction in rehabilitation of adult stroke patients with spasticity and contracture, and the importance of multidisciplinary collaboration including surgeons in stroke rehabilitation to optimize functional outcomes.

Keywords
stroke, rehabilitation, spasticity, contracture, surgical reconstruction, paralytic reconstruction

Stroke is a major burden globally, being the second most common cause of death (11.8%) and the third most common cause of disability (4.5% of disability-adjusted life-years from all causes) worldwide.[1] With improved health education and inpatient treatment, the incidence and case fatality of stroke have declined over the past two decades, but the absolute number of people with stroke and demand for rehabilitation and long-term care have actually increased.[2] Stroke requires a long duration of physical rehabilitation despite recent advances in rehabilitative strategies and stroke care.[3] Post-stroke spasticity and contracture remain a common problem, leading to significant functional impairment, pain, disability and reduced quality of life.

Spasticity is characterised by involuntary muscle hyperactivity with a velocity-dependent increase in tonic stretch reflexes in diseases with an upper motor neuron syndrome presentation. These neuromotor factors can take various forms including spasticity sensu stricto, rigidity, dystonia, spasm and a mixture of these elements.[4] Spasticity, if left untreated, can lead to muscle and joint stiffness, and ultimately contracture. In a functional limb, this can result in a restricted range of motion, pain and limitation in activities of daily living (ADL). Even in a non-functional limb, severe spasticity can lead to skin hygiene issues and difficulty in nursing care. The goal of management in post-stroke spasticity is to facilitate splintage use, improve patient mobility and functional status, increase range of motion in major joints, and improve hygiene and body image.

Reconstructive surgery is an effective strategy for managing spasticity and contracture following adult stroke, and can serve as an adjunct to traditional rehabilitative therapy when the effect of such is maximised. Despite reconstructive procedures being performed for over two decades, surgery is often not included in the rehabilitation-focused guidelines for patients with spasticity.[5] Substantial underutilisation of upper and lower extremity reconstructive surgery for post-stroke spasticity is seen globally. For example, less than 1% of eligible and appropriate candidates underwent surgery in United States data.[6] This article aims to provide an overview of surgical reconstruction for limb spasticity and contracture and discuss the rationale, techniques and outcomes of these interventions to enable physicians and allied health professionals to better understand and appreciate surgical reconstruction as a rehabilitative strategy for adult stroke. Evidence in this review was gathered from extensive literature search from the PubMed library and the authors' own experience in stroke patient management. Ethical approval and patient consent were not required for this study as it is based on review of the literature and does not involve identifiable patient information.

Non-surgical management

First-line treatment for post-stroke spasticity remains non-surgical. The rationale is to learn motor activities and utilise undamaged areas of the brain. Standard measures include splintage for positioning, manual stretching exercises and physical therapy. Hand splints are widely used in patients post-stroke, but there is insufficient evidence to support the effectiveness in reducing post-stroke spasticity[7] and their use is advised against as a routine practice in stroke rehabilitation guidelines.[8] Physical therapy consists of a wide variety of interventions, including motor learning programmes, sensory stimulation, strength training and postural control.[9] However, physical therapy alone cannot always overcome muscle spasticity where the inhibitory pathway of tone reflexes is deranged, and will become more of a maintenance nature once the rehabilitative plateau has been reached. Oral skeletal muscle relaxants provide systemic anti-spastic effects, but have high rate of adverse effects and fair evidence of effectiveness.[10]

Botulinum toxin injection

Botulinum toxin type A (BoNT-A) inhibits acetylcholine release from neuromuscular junctions, reducing muscle hyperactivity and spasticity. Intramuscular injections of BoNT-A into spastic muscle groups are proven safe and effective in both upper limb and lower limb spasticity,[11] and are recommended as a first-line local treatment for spasticity after adult stroke in national guidelines.[12] Weakening a spastic agonist at the joint achieves better muscle balance and facilitates motor learning. The effect of improved motor function can be observed even after the effect of BoNT-A wears off after 6 months. Early use of BoNT-A injections has also been shown to reduce contracture development without interference with arm function recovery.[13]

Surgical reconstruction

Surgical interventions aim to provide a long-lasting effect on spasticity relief.[14] Appropriate patients for surgical interventions include patients who have failed conservative or non-surgical treatment, have severe contractures that are functionally disabling, and those who have received BoNT-A injections with good relief but recurrence of motor functional limitation after wearing-off of the drug effect. The primary goals of surgical reconstruction are the same as spasticity management in general: improving functional outcome, enhancing quality of life and preventing secondary complications such as joint contracture, deformity and pain.

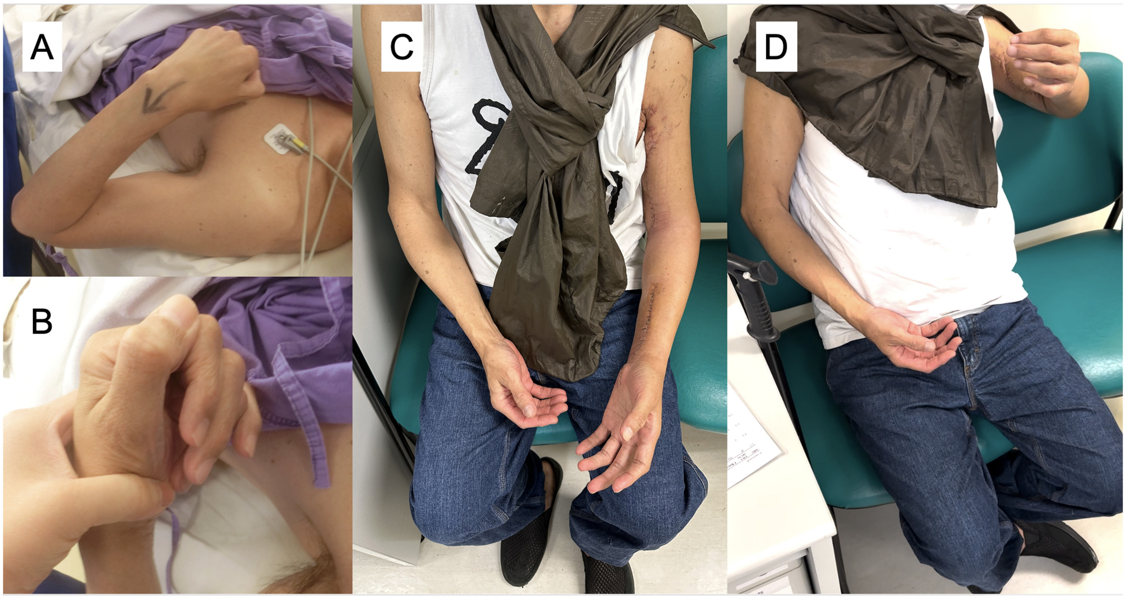
The main considerations in terms of surgical choice include whether the limb is functional or not; whether there is volitional control in specific muscle groups, and whether it is pure muscle spasticity or combined with muscle contracture. Spasticity surgery can be performed on tendons, muscles, nerves and even joints, depending on the functional status, severity and coexisting pathology. A combination of techniques can be used to achieve an antagonistic effect. Multiple spastic muscle groups are often operated on in one surgery ('Single Event Multi-level Surgery')[15] to achieve optimal outcome and avoid repeated anaesthesia (Figure 1).

Tendon lengthening, release or transfer

Fractional lengthening, where multiple small transverse cuts are made at the musculotendinous junction, preserves a higher degree of residual muscle power by altering muscle sarcomere length and changing the force-generating capacity of the muscle, without over-weakening or completely deactivating the muscle.[16] The tendinous part is partially cut, while the integrity of the underlying muscle fibres is maintained. Anatomical variation in the musculotendinous junction exists among different muscles and the exact surgical description varies according to the operated muscles and the amount of lengthening targeted, which is typically 0.5–1.5 cm.[17] When a higher degree of lengthening is desired, lengthening in the tendon substance, such as Z-lengthening of biceps tendon in the case of fixed elbow contracture, can offer significant improvement in range of motion when combined with release of the tight peri-articular soft tissue. Multiple studies have shown favourable results with increased range of motion, improved cosmesis and function in the elbow, wrist and fingers.[18] In the series by Keenan *et al*., all non-functional hands gained improvement in posture and resolution of hygiene problems after fractional lengthening of finger flexors, while 91% of potentially functional hands improved their spastic hand function score by a mean of 3.7 points.[19] Namdari *et al*. also demonstrated that 94% of patients were pain-free after elbow flexor release, with improved elbow flexion contracture from 78 degrees to 17 degrees.[20] However, striking the midpoint between inadequate lengthening and over-lengthening (or even complete disruption of the muscle-tendon unit) can sometimes be difficult to achieve and may lead to suboptimal results.[19] Biomechanical studies have shown significant reduction in tensile strength and load to failure after lengthening, where precaution needs to be exercised even in the postoperative rehabilitation period.[21] However, there is currently no report of differences in rupture rate among various lengthening techniques.

In a non-functional limb without voluntary control of muscles or with severe contracture, tenotomy often produces high degree of release, which can be used in pectoralis major and latissimus dorsi for a spastic adducted shoulder with internal rotation.[4] The resting posture can be maintained by finetuning the degree of tenotomy, especially in muscles with multiple muscle heads, to avoid reverse deformity after release. Namdari *et al*. demonstrated a high rate of patient satisfaction (97%) and pain-free outcome (95%) at a mean follow-up of 14.3 months.[22] A similar effect of release can also be achieved with modifications of tendon transfer in non-functional hands with clenched fist deformity, by performing superficialis-to-profundus tendon transfer in the forearm to open up fingers without losing the appearance of finger flexion cascade.[23] Heijnen *et al*. showed an excellent long-term outcome with all operated hands for clenched fist maintaining fully

Figure 1. A: Preoperative resting posture with the elbow in flexion. B: Preoperative resting posture with clenched fist deformity. C: Postoperative photo showing resting posture after 'single event multi-level surgery', with fractional lengthening of pectoralis major muscle, selective neurectomy of musculocutaneous nerve, fractional lengthening of biceps and flexor pronator mass, superficialis-to-profundus tendon transfer, and deep branch of ulnar nerve neurectomy performed. D: Maintaining the ability of active elbow flexion after surgery without over-weakening.



opened at 19 months, and permanent improvement in hygiene and pain reduction.[24] However, complications such as secondary intrinsic-plus hand deformity and swan neck deformity of fingers are possible after superficialis-to-profundus transfer[23] and the authors now routinely perform deep motor branch of ulnar nerve neurectomy at the same time to avoid this complication.

Apart from release or lengthening, tendon transfers from dispensable muscles can be helpful. For example, a tendon transfer to the extensor carpi radialis brevis is commonly performed to provide active wrist extension and improve wrist positioning.[15] This achieves wrist flexion-extension balance, which improves joint biomechanics and preserves wrist mobility as compared to joint fusion.

Neurectomy

Apart from operating on tendons and muscles, spasticity management can also be targeted at the nerve level by disrupting the reflex arc that causes muscle hyperactivity. Neurectomy can be performed at different levels, ranging from main trunks (neurectomy), to main motor branches (partial motor neurectomy), primary branches (selective neurectomy) or even secondary branches (hyperselective neurectomy).[25] While cutting the entirety of a peripheral nerve causes sensory loss and muscle weakness, selective neurectomy after internal neurolysis, or hyperselective neurectomy after dissection to the point of motor rami into the target muscle, can be performed by hand surgeons with microsurgical skillsets to avoid damage to sensory branches and over-weakening of muscles. Hyperselective neurectomy provides highly selective denervation to secondary motor branches and demonstrates promising outcome with an effective reduction of spastic tone without compromising muscle strength in the prospective study by Leclercq *et al.*[26] The resting posture of elbow improved from 74 degrees of flexion to 36 degrees of flexion postoperatively, and the effect was well maintained at 38 degrees of flexion at mean follow-up of 31 months. Main complication of selective neurectomy is sensory disturbance with up to 10% of neurapraxia reported[27]; however, this was not seen in Leclercq's series of hyperselective neurectomy as all the sensory branches were preserved.

To predict the success of selective neurectomy, diagnostic nerve blocks can be performed for immediate assessment of spasticity. Alternatively, BoNT-A injection as mentioned above provides a longer assessment window as the effect lasts for several months usually and functional improvement in ADL can be assessed.

Joint fusion

Joint fusion or arthrodesis, despite sacrifice of the motion segment, is sometimes the preferred treatment in cases of advanced deformity or joint instability. Wrist fusion for example, commonly performed with proximal row carpectomy in severe wrist flexion contracture, provides a stable joint that aids distal function including hand opening and grip, and prevents future deformity recurrence.[28] It has high patient satisfaction and ADL improvement rate, but may occasionally require elective removal of implants due to impingement.[15]

Lower limb reconstruction

The same treatment principle can also be applied to reconstruction of lower limbs, with surgery targeting tendons (lengthening/transfer), muscles (lengthening) and nerves (neurectomy) as appropriate.[14] Common indications include frequent tripping and recurrent ankle sprain due to dynamic ankle inversion deformity with spastic tibialis posterior, equinus ankle deformity with spastic gastrocsoleus muscle, and scissoring gait with spastic hip adductors. This is particularly helpful when conservative treatment with external orthosis is ineffective, and for those who cannot tolerate orthosis use. For example, selective neurectomy of tibial nerve can selectively reduce spasticity in the posterior compartment muscles while preserving sensation in the sole.[14] This allows patients to achieve a plantigrade and stable foot without using an ankle foot orthosis. It also relieves toe flexor spasticity, which causes discomfort and callosities over the pulp and toe interphalangeal joints.

Factors to consider before recommending surgery

Preoperative BoNT-A injection

Preoperative BoNT-A injection predicts surgical outcome and facilitates surgical decision. It provides information on whether surgical release (which has a similar effect to BoNT-A injection but is more long-lasting) targeting the spastic muscle group can provide symptomatic relief and functional improvement. It also facilitates surgeons in choosing the optimal surgical plan: whether there is coexisting muscle spasticity and contracture where capsular release and extensive lengthening are required; and whether the antagonist muscles have no active control or are just masked by the agonist muscle spasticity (where balance between the two can be achieved by simple lengthening).

BoNT-A injection also serves as a trial that is reversible once the effect of BoNT-A wears off, where undesirable effects can be brought to the surface and avoided later in the surgical planning. For example, injections to the flexor pollicis longus muscle may cause over-weakening and therefore difficulty in performing the pinch grip, so some may regard such release as detrimental to their current function even though there is a relief of spasticity. Patients can therefore be actively involved in the overall planning of reconstruction as they can have a subjective perspective of the possible outcome of surgery. This allows patients and surgeons to make a joint decision in determining which muscles to target. It ensures an optimal functional outcome which preserves functions that patients still possess and value, before irreversible surgery is performed.

Patient selection and timing of surgery

Patient selection is crucial as not all patients are suitable candidates for surgical reconstruction. It is best to target muscle spasticity, imbalance and contracture that causes significant functional impairment, but selective control of muscle, coordination and weakness may not show significant improvement as the effect of primary insult to the central nervous system remains unchanged. It is also difficult to correct dystonia by procedures that correct spasticity. Careful assessment by a multidisciplinary team is essential to determine the eligibility and there is no cookbook approach for spasticity surgery. In general, patients who are motivated, have muscle spasticity or contracture that responded favourably (whether partially or transiently) to BoNT-A injection, and those who have reached the rehabilitative plateau with non-surgical management are good candidates for surgical reconstruction.

Timing is also critical where surgical interventions should be considered only when spasticity and contracture have stabilised, after an initial period of rehabilitation therapy, splintage, mobilisation exercise and non-surgical interventions. The golden period of first 6 months for motor re-learning should be fully utilised. The recommended timeframe is 9–12 months after the primary brain insult.[14,18] The final functional outcome is also better when there is pure muscle spasticity without joint contracture, compared to contracted muscles and joints where more extensive surgeries are required. Nevertheless, late surgery is still beneficial by restoration of muscle balance and correction of developed contractures.

Limitations and complications

Patients should also be informed of the potential complications and risks as with all surgical interventions. Apart from specific procedural complications mentioned in the above sections, general surgery-related complications such as wound infection, neurovascular damage, limited improvement or overcorrection are also possible which may necessitate further surgery.[5] An overall complication rate of 9.4% and a re-operation rate of 2% were reported in the systematic review by Jarratt Barnham *et al.*,[29] with 9% of patients developing a recurrent or new upper limb deformity postoperatively. Overall, spasticity surgery is generally safe with very few significant complications reported, but surgeons should be transparent with patients regarding the realistic goal and complication profile preoperatively.

The postoperative rehabilitation protocol should also be well explained to patients before surgery. After surgical reconstruction, adjunct rehabilitative therapy remains important to ensure the effect of release and spasticity relief is carried onwards. Various rehabilitative interventions have been shown to enhance cerebral plasticity and promote functional recovery,[30] and the same phenomenon is seen after spasticity surgery as well.[31] Consistent postoperative motor and functional training is therefore synergistic to surgery by further enhancing the brain plasticity and optimising the power of surgery. Patients who are unmotivated, not willing to cooperate with adjunct therapy, or without good social support are often not the best candidates for surgery. Shared decision-making with patients and carers, compliance with intensive rehabilitation protocol and social support from family members are crucial to surgical success.

The way forward

Further research

Novel surgical treatment modalities are being studied which could potentially further improve surgical outcomes. Contralateral C7 nerve transfer from the non-paralysed limb to the paralysed and spastic side was shown to have significant improvement in spasticity compared to rehabilitation alone at 12 months in a single-centre trial.[32] However, these results have not been replicated by other published cohorts at the moment and require further research on the underlying pathophysiology and clinical safety in such a highly technical procedure.[33] Distal nerve transfers in combination with selective neurectomy could also potentially augment the muscle power in the weak muscle groups apart from reducing spasticity, but this is currently still limited to anatomical feasibility studies only without published clinical results.[34]

The majority of studies reported in the literature have heterogeneous background parameters of patients, as presentation of post-stroke disability is highly variable among individuals. Every patient presents with different levels of limb paralysis, spasticity and contracture affecting different joints, so surgeons often need to employ a tailor-made combination of procedures for each individual. This causes challenges in conducting research with high level of evidence using randomised controlled trials and meta-analyses. Nevertheless, studies with larger cohorts, multicentre collaboration, and longer follow-up periods are required to facilitate evidence-based decisions for patients and healthcare professionals.

Incorporation of surgical rehabilitation in stroke care

While non-surgical treatments remain the first line of management for post-stroke spasticity and contracture, surgical interventions offer hope for patients who still have a residual functional deficit after these treatments. Apart from providing improvement in function and quality of life, surgery also significantly reduces long-term societal healthcare costs incurred, by reducing the need for prolonged physical therapy or chemodenervation treatments in the long run.[35]

Multidisciplinary collaboration and a patient-centred approach are essential in making treatment decisions and ensuring an optimal patient outcome. However, surgery should not be the last resort to manage complications brought by severe contractures, but a means to maximise motor performance potential of the neuromuscular system of patients. It should be included as one of the rehabilitative strategies after adult stroke ('surgical rehabilitation'), alongside with physical therapy, occupational therapy, speech therapy and pharmacological management. However, there are few centres around the world with dedicated multidisciplinary units for stroke rehabilitation that include surgeons in the team, despite the immense disease burden of stroke worldwide. While surgery might not be suitable for all patients with post-stroke spasticity, it would be beneficial for all patients to have the opportunity to be evaluated by surgeons to determine their eligibility for surgical intervention. The authors recommend timely referral to dedicated specialists for spasticity management, whether surgical or non-surgical, and establishment of multidisciplinary units consisting of rehabilitation specialists and experienced surgeons to optimise functional outcomes in stroke patients.

Declarations

Competing interests: The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding: The authors received no financial support for the research, authorship, and/or publication of this article.

Ethical approval: Ethical review and approval were waived by the Institutional Review Board for this study as it is based on a review of the literature and does not involve identifiable patient information.

Contributorship: MMTC and WYI: conceptualisation. MMTC: methodology, data curation, and writing – original draft preparation. WYI: writing – review and editing and supervision.

Provenance: Not commissioned, peer reviewed by Cher Bing Chuo.

odds ratioconfidence intervalD iD: Marvin Man Ting Chung https://orcid.org/0000-0002-0620-1677

References

1. Feigin VL, Norrving B and Mensah GA. Global burden of stroke. *Circ Res* 2017;120(3):439–448.
2. Woo J, Ho SC, Goggins W, Chau PH and Lo SV. Stroke incidence and mortality trends in Hong Kong: implications for public health education efforts and health resource utilisation. *Hong Kong Med J* 2014;20(3 Suppl 3):24–29.
3. Ferrarello F, Baccini M, Rinaldi LA, et al. Efficacy of physiotherapy interventions late after stroke: a meta-analysis. *J Neurol Neurosurg Psychiatry* 2011;82(2):136–143.
4. Dressler D, Bhidayasiri R, Bohlega S, et al. Defining spasticity: a new approach considering current movement disorders terminology and botulinum toxin therapy. *J Neurol* 2018;265(4):856–862.

5. Hashemi M, Sturbois-Nachef N, Keenan MA and Winston P. Surgical approaches to upper limb spasticity in adult patients: a literature review. *Front Rehab Sci* 2021;2:709969.
6. Beutel BG, Marascalchi BJ and Melamed E. Trends in utilization of upper extremity reconstructive surgery following traumatic brain injury and stroke. *Hand (N Y)* 2020;15(1):35–40.
7. Lannin NA and Herbert RD. Is hand splinting effective for adults following stroke? A systematic review and methodological critique of published research. *Clin Rehabil* 2003;17(8):807–816.
8. Harvey LA, Katalinic OM, Herbert RD, Moseley AM, Lannin NA and Schurr K. Stretch for the treatment and prevention of contractures. *Cochrane Database Syst Rev* 2017;1(1):CD007455.
9. Shahid J, Kashif A and Shahid MK. A comprehensive review of physical therapy interventions for stroke rehabilitation: impairment-based approaches and functional goals. *Brain Sci* 2023 Apr 25;13(5):717.
10. Chou R, Peterson K and Helfand M. Comparative efficacy and safety of skeletal muscle relaxants for spasticity and musculoskeletal conditions: a systematic review. *J Pain Symptom Manage* 2004;28(2):140–175.
11. Aktürk S, Büyükavcı R and Ersoy Y. Functional outcomes following ultrasound-guided botulinum toxin type A injections to reduce spastic equinovarus in adult post-stroke patients. *Toxicon* 2018;146:95–98.
12. Simpson DM, Hallett M, Ashman EJ, et al. Practice guideline update summary: botulinum neurotoxin for the treatment of blepharospasm, cervical dystonia, adult spasticity, and headache: report of the guideline development subcommittee of the American Academy of Neurology. *Neurology* 2016;86(19): 1818–1826.
13. Lindsay C, Ispoglou S, Helliwell B, Hicklin D, Sturman S and Pandyan A. Can the early use of botulinum toxin in post stroke spasticity reduce contracture development? A randomised controlled trial. *Clin Rehabil* 2021;35(3):399–409.
14. Allart E, Sturbois-Nachef N, Salga M, Rosselin C, Gatin L and Genêt F. Neuro-orthopedic surgery for equinovarus foot deformity in adults: a narrative review. *J Foot Ankle Surg* 2022;61(3):648–656.
15. Tranchida GV and Van Heest A. Preferred options and evidence for upper limb surgery for spasticity in cerebral palsy, stroke, and brain injury. *J Hand Surg (European Volume)* 2020;45(1):34–42.
16. Mathewson MA, Ward SR, Chambers HG and Lieber RL. High resolution muscle measurements provide insights into equinus contractures in patients with cerebral palsy. *J Orthop Res* 2015;33(1):33–39.
17. Arnaout A and Leclercq C. Fractional lengthening of the forearm flexor muscles: anatomic study. *J Hand Surg Am* 2022;47(8):792.e1–792.e5.
18. Rhee PC. Surgical management of the spastic forearm, wrist, and hand: evidence-based treatment recommendations: a critical analysis review. *JBJS Rev* 2019;7(7):e5.
19. Keenan MAE, Abrams RA, Garland DE and Waters RL. Results of fractional lengthening of the finger flexors in adults with upper extremity spasticity. *J Hand Surg Am* 1987;12(4):575–581.
20. Namdari S, Horneff JG, Baldwin K and Keenan MA. Muscle releases to improve passive motion and relieve pain in patients with spastic hemiplegia and elbow flexion contractures. *J Shoulder Elbow Surg* 2012;21(10):1357–1362.
21. Do D-H, Heineman N, Crook JL, Ahn J, Sommer DM and Koehler DM. Fractional lengthening of forearm flexor tendons: a cadaveric biomechanical analysis. *J Hand Surg Am* 2024 May 3:S0363-5023(24)00149-7.
22. Namdari S, Alosh H, Baldwin K, Mehta S and 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;20(5):802–806.
23. Peraut E, Taïeb L, Jourdan C, et al. Results and complications of superficialis-to-profundus tendon transfer in brain-damaged patients, a series of 26 patients. *Orthop Traumatol: Surg Res* 2018;104(1):121–126.
24. Heijnen IC, Franken RJ, Bevaart BJ and 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):675–678.
25. Mikalef P and Power D. The role of neurectomy in the management of spasticity of the upper limb. *EFORT Open Rev* 2017;2(11):469–473.
26. Leclercq C, Perruisseau-Carrier A, Gras M, Panclera P, Fulchignoni C and Fulchignoni M. Hyperselective neurectomy for the treatment of upper limb spasticity in adults and children: a prospective study. *J Hand Surg Eur Vol* 2021;46(7):708–716.
27. Maarrawi J, Mertens P, Luaute J, et al. Long-term functional results of selective peripheral neurotomy for the treatment of spastic upper limb: prospective study in 31 patients. *J Neurosurg* 2006;104(2):215–225.
28. Pomerance JF and Keenan MAE. Correction of severe spastic flexion contractures in the nonfunctional hand. *J Hand Surg Am* 1996;21(5):828–833.
29. Jarratt Barnham I, Alahmadi S, Spillane B, Pick A and Lamyman M. Surgical interventions in adult upper limb spasticity management: a systematic review. *Hand Surg Rehab* 2022;41(4):426–434.
30. Hara Y. Brain plasticity and rehabilitation in stroke patients. *J Nippon Med Sch* 2015;82(1):4–13.
31. Su F and Xu W. Enhancing brain plasticity to promote stroke recovery. *Front Neurol* 2020;11:554089.
32. Zheng M-X, Hua X-Y, Feng J-T, et al. Trial of contralateral seventh cervical nerve transfer for spastic arm paralysis. *N Engl J Med* 2017;378(1):22–34.
33. Alawieh AM, Au Yong N and Boulis NM. Contralateral C7 nerve transfer for stroke recovery: new frontier for peripheral nerve surgery. *J Clin Med* 2021;10(15):3344. doi:10.3390/jcm10153344
34. Jaloux C, Bini N and Leclercq C. Nerve transfers in the forearm: potential use in spastic conditions. *Surg Radiol Anat* 2022;44(8):1091–1099.
35. Reddy S, Kusuma S, Hosalkar H and Keenan MA. Surgery can reduce the nonoperative care associated with an equinovarus foot deformity. *Clin Orthop Relat Res* 2008;466(7):1683–1687.