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Surgical approach to forearm pronation deformity in patients with cerebral palsy: a systematic review

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Background: **Pronation deformity in patients with cerebral palsy can have a major impact on upper limb functionality. There is lack of consensus in the literature about the preferred surgical technique to address this deformity.**
Study aim: **To evaluate and synthesize the outcome of different surgical techniques for pronation deformity in patients with cerebral palsy.**
Methodology: **The databases MEDLINE and Embase were searched for publications up to December 2021. Articles were considered eligible for inclusion when the included patients had a pronation deformity caused by cerebral palsy and results of surgical intervention for pronation deformity were examined. Evaluation of the quality of the retrieved study was conducted using the MINORS tool. Meta-analysis was not possible due to the heterogeneity of interventions and reported outcomes.**
Results: **Nineteen studies, involving 475 patients and eight different techniques were included. All studies reported gain of active supination in most patients. The effect of surgery on functional gain was less clear and there was a large heterogeneity of reported functional outcome measures. There were 46 reported complications. Overall quality of study design was poor, illustrated by the average MINOR score of 6.9/16. Overall, there is a high risk of bias due to poor internal and external validity of the studies.**
Conclusion: **Despite positive reports on gain in supination and functionality after most procedures addressing pronation deformity in CP patients, no conclusions can be drawn concerning the preferred technique due to the low quality of the evidence.**

Keywords: cerebral palsy, pronation deformity, spasticity

INTRODUCTION

The most common motor manifestation of cerebral palsy (CP) is motor spasticity, which can lead to joint deformity and contractures due to muscle imbalance across the joint[1].

In the upper extremity, the typical pattern of spastic joint deformities include shoulder internal rotation, elbow flexion, forearm pronation, wrist flexion and ulnar deviation, thumb-in-palm, and finger swan neck or clenched fist deformity. It has been reported that upper-extremity problems are found in as many as 83% of children with cerebral palsy and forearm pronation deformity is one of the most common features[2].

Hypertonicity of the pronator teres (PT) and pronator quadratus muscles (PQ), with or without weakness of supinating muscles is the primary cause[3]. This deformity significantly interferes with bimanual use of the upper limb, necessary in two-handed manipulation of objects, such as during personal hygiene and feeding activities[4].

The lack of active supination is often found in conjunction with a flexion deformity of the wrist. The flexed position of the wrist further impedes upper limb function[5].

Therapy to improve supination and upper limb function in general is multidisciplinary and multimodal, including physiotherapy, pharmacological and surgical treatment. Surgical procedures in properly selected patients are appropriate to improve forearm position and function[6]. However, surgical procedures are performed only in less than 20% of CP patients with upper limb involvement, in contrast with more frequent surgical therapy in the lower limbs[3].

A possible cause for the reluctance to proceed to surgery is the lack of consensus in the literature about the preferred surgical techniques and outcomes. The aim of this study is to provide an extensive review, which evaluates all described surgical techniques

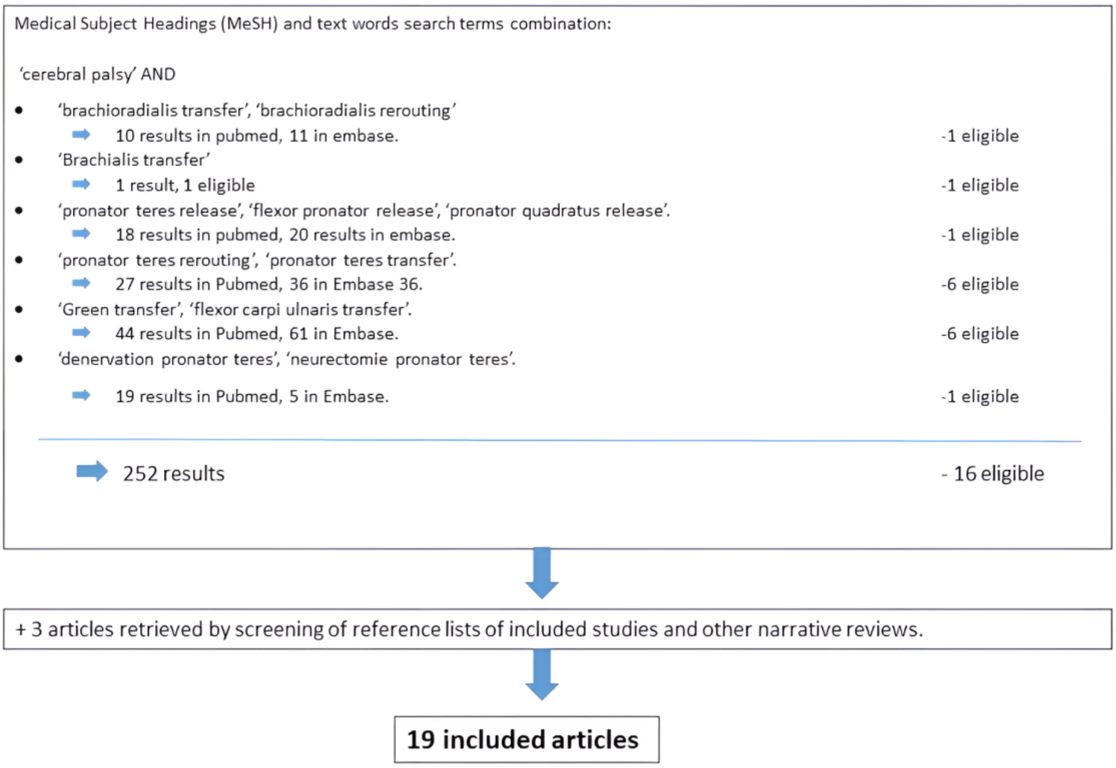

Fig. 1 — Used Medical Subject Headings (MeSH) and text words search terms and associated results.

utilised and their outcome for pronation deformity in patients with cerebral palsy.

METHODOLOGY

1. Inclusion criteria

The databases MEDLINE and Embase were searched for publications up to December 2021.

Articles were considered eligible for inclusion when they met the following criteria:

- Included patients were CP patients with pronation deformity
- Results of surgical interventions for pronation deformity were examined.

Studies that do not focus solely on this patient group, were only included if data on CP patients and pro-supination function were reported separately. RCT's as well as cohort studies and case-control studies were eligible for inclusion. Studies were excluded if no full-text was available in English or French.

Primary outcomes included analytical assessment and functional measures. Secondary outcome measures include patient satisfaction or patient reported outcome questionnaires and complication rate.

2. Search strategy

The comprehensive literature search started with the reference set of the review article of Gschwind et al.[7]. This reference set was completed by using the search terms 'pronation deformity' and 'cerebral palsy', resulting in 41 articles in MEDLINE. On the basis of this reference set, all types of procedures for correction of pronation deformity were selected and they were used to derive the used Medical Subject Headings (MeSH) and text words search terms. The terms used and associated results in the used databases can be found in figure 1.

Titles and abstracts of all identified citations were screened to identify relevant articles and full papers obtained if the paper had passed the first eligibility screening or insufficient information was provided in the abstract. Reference lists of included studies and other narrative reviews were also searched.

The standardized data extraction form included the collection of the following: surgical procedure, level of evidence, inclusion and exclusion criteria, number of patients, age of patients, length of follow up, patient classification according to Gschwind, CP type, gain in active supination, gain in functionality, patient satisfaction and complications.

Evaluation of the quality of the retrieved study was conducted using the MINORS tool by two reviewers (including the main author). MINORS is a valid instrument designed to assess the methodological quality of non-randomized surgical studies, whether comparative or non-comparative[8]. Meta-analysis was not possible due to the heterogeneity of patient characteristics, interventions and reported outcomes. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed wherever applicable.

RESULTS

Using the search strategy as described above, 252 results were retrieved. After eliminating duplicates and screening title, abstract and finally full text, 16 articles remained. Screening of reference lists of included studies and other narrative reviews, yielded 3 more articles (see fig.1).

The total number of participants in the 19 studies was 475. The results of eight different surgical techniques were reported. Patient age ranged from 4 to 65 years. Average follow up time ranged from 6 months to 17,5 years. An overview of the study characteristics can be found in table I.

All studies reported a gain in supination in most patients. The effect of surgery on functional gain was less clear and there was a large heterogeneity of reported functional outcomes: in the 19 articles, 10 validated measurement tools of function and 3 non validated tools were used. Nine articles reported functional gain according to one or more measurement tools, 4 studies reported no functional gain in at least one measurement tool. Patient satisfaction was reported in 4 articles and was reported as satisfying. An overview of the outcome measures can be found in table II. There were 46 reported complications, consisting almost only of overcorrection deformity or persistence/ recurrence of the primary deformity (cfr table IV and V).

No randomised controlled trials or controlled clinical trials were found. The best available evidence were Level IV prospective case series that compared pre- and post-operative assessment. Very often patients underwent concomitant orthopaedic procedures in addition to the procedure of interest. Overall quality of study design was poor, illustrated by the average MINOR score of 6.9/16. In general, there is a high risk of bias due to poor internal and external validity of the studies.

DISCUSSION

Discussion considering the surgical technique

In summary, eight surgical techniques were found in the literature to address pronation deformity in CP patients (These are bold in table III). The main principle of surgery is to decrease tone in overactive muscle groups with release procedures and/or to augment weak muscles by tendon transfers. Joint or soft tissue contractures have to be released first to allow passive motion.

Roughly a subdivision can be made into 2 groups:

1. Procedures for pronation deformity only
2. Procedures for pronation deformity and wrist flexion deformity

Below, the techniques and their outcomes are discussed and a mutual comparison is made where possible.

1. Procedures exclusively for pronation deformity of the forearm

A. Brachioradialis rerouting

Cheema et al compared the biomechanical efficacy of 3 tendon transfers in simulated supination in ten cadaveric forearms. Brachioradialis rerouting proved to be the second most effective, after the flexor carpi ulnaris (FCU) transfer[9].

Indeed, Ozkan et al demonstrated a mean increase in active supination of 81° (range 40-140°) after brachioradialis rerouting in a clinical study[10]. However, this procedure was combined with a Z-pronator lengthening, the number of included patients was small and the study was of limited quality.

Ozkan et al also reported on the outcome of brachialis transfer in a clinical study[11]. There was only a clear gain in supination in half of the patients and the quality of this study was limited.

More studies are needed to establish brachioradialis rerouting or brachialis transfer as a valid technique for addressing pronation deformity in patients with cerebral palsy.

B. Pronator release

The Pronator teres (PT) muscle provides 79% of the pronation torque, whereas the pronator quadratus (PQ) contributes 21%[12]. In theory most of the deforming torque force is eliminated by releasing them, which can lead to a significant correction of the pronation

Table I. — Overview of study characteristics.

Studie	Procedure	Number of patients	Level of evidence	MINORS	Mean Length of folluw-up
Brachioradialis transfer					
Ozkan et al, 2004	Brachioradialis rerouting + PQ tenotomy and Z-lengthening of PT	5	IV	2/16	?
Brachialis transfer					
Ozkan et al, 2012	Brachialis muscle transfer (+ release of PT/ PQ/IO membrame)	4	IV	5/16	15,5 months (range 10-20)
Releases					
Thevenin et al, 2013	Flexor- pronator slide.	50 (11CP)	IV	8/16	26 months (range 3 -124)
Strecker et al, 1988	PT release vs PT transfer	Tenotomy: 16 Rerouting: 41	IV	7/24	Tenotomy: 94 months Rerouting 21 months
PT rerouting					
Bunata et al, 2006	PT rerouting	31	IV	7/16	39 months (range 8 to 63)
Rothe et al, 1993	PT rerouting + additional procedures	17	IV	8/16	2.6 years (range 0.9 to 4.6 years.)
Cobeljic et al, 2015	Pronator teres transposition to ECRB or Pronator rerouting or Pronator rerouting with Pronator quadratus myotomy	61	IV	10/16	17.5 years (range 3–41 years).
Kreulen et al, 2004	Pronator teres rerouting AND FCU transfer to ECRB	10	III	11/16	14 months average (range 11–19 months)
PT to ECRB					
Singh et al, 2020	Pronator teres to ECRB transfer	15	IV	9/16	6 months
Ho et al, 2015	Pronator teres to ECRB transfer	17	IV	7/16	46 months (range 13 to 60)
FCU transfer					
Beach et al, 1991	FCU to ECRB + concomitant procedures (some involving PT)	40	IV	7/16	5 years and 3 months (average)
Thometz et al, 1988	FCU to ECRB + PT release in some patients (8)	25	IV	4/16	8 years 7 months
Wolf et al, 1998	FCU to ECRB/ECRL/EDC + several other procedures (some involving PT)	16	IV	7/16	4 years average (range 1 to 9)
El Said, 2001	FCU to ECRB + flexor-pronator release	35	IV	5/16	4 years
Mifsud et al, 2020	FCU to ECRB transfer +/- PT re-routing +/- elbow flexor releases +/- finger flexor muscle releases.	13	IV	8/16	14 months (range 9 to 21)
Chibirov et al, 2020	modified FCU transfer + several other procedures (some involving PT)	25	IV	5/16	12 months
Neurectomy					
Helin et al, 2018	Neurectomy of PT	22	IV	5/16	32.6 months average (range 5–76)
Gras et al, 2017	Neurectomy of PT (subgroup of study)	12	IV	8/16	15 months
Puligopu et al., 2011	Neurectomy in the upper limb of children with cerebral palsy (subgroup PT)	20	IV	9/16	10 months (range 6 to 24)

deformity[4]. The pronator release can be divided into 2 techniques: the flexor-pronator origin slide and the PT tenotomy. The flexor-pronator origin slide is discussed below, as this technique also has an impact on wrist flexion deformity

Table II. — Overview of outcomes.

Studie	Procedure	Gain in active mobility	Gain in functionality/ QOL	Patient satisfaction
Brachioradialis rerouting				
Ozkan et al, 2004	Brachioradialis rerouting + PQ tenotomy and Z-lengthening of PT	81° mean supination gain (ranges 40-140°) (no p-value given)	?	?
Brachialis transfer				
Ozkan et al, 2012	Brachialis muscle transfer (+ release of PT/PQ/IO membrame)	29° supination (range 0-60°) (no p-value given)	?	?
Releases				
Thevenin et al, 2013	Flexor- pronator slide.	67° ± 25° mean gain in wrist extension (with fingers extended) (range, -10° to 110°) (p<0,01)	Increase in Zancolli and House classifications score (p < 0.01)	?
Strecker et al, 1988	PT release vs PT transfer	– Tenotomy: 54,5° average gain in supination – Rerouting 78,1° average gain in supination (no p-value given)	?	?
PT rerouting				
Bunata et al, 2006	PT rerouting	– 65° average gain in supination (range -25° to 115°) (p<0,001) – dynamic positioning from average 26° pronation preoperative to 7° postoperative (p<0,001)	• 30 of the 31 patients gained the ability to hold a cup of water in the involved hand. • 9 children positioned the hand in supination during grasp. no validated tool	?
Rothe et al, 1993	PT rerouting + additional procedures	mean position of forearm range improved from 64° pronation preoperative to 22° pronation postoperative (p<0,01)	Modified House scale score: from 3.7 to 5.5 (p<0,01)	?
Cobeljic et al, 2015	Pronator teres transposition to ECRB or Pronator rerouting or Pronator rerouting with Pronator quadratus myotomy	75° mean supination gain (p < 0.001) No statistically significant difference between the three operative techniques	• All techniques: improved MEPS (p <0.001) • PT rerouting + PQ myotomy: improved Functional Classification system for the upper extremity score (p < 0.05) • PT rerouting procedure: improved Quick Dash score (p < 0.05)	?
Kreulen et al, 2004	Pronator teres rerouting and FCU transfer to ECRB	– 63° average gain in supination (SD 35,1°, p<0,001) – 23° mean increase of forearm ROM (SD 37,5°, p=0.013)	no measurement of function	?
PT to ECRB				
Singh et al, 2020	Pronator teres to ECRB transfer	– 67° mean gain in supination (SD 16.3, range 26° to 90°, p < 0.05). – 32° mean change in the forearm resting position (p<0,05) – 15° mean active wrist extension gain (SD 4.9, range 10° to 20°, p < 0.05)	• mean increase in UEFI Score: 7.0 (p < 0.001). • No significant improvement on MACS or House scale	median patient satisfaction score: 3 (IQR 2.5 to 3.5) (0 is the worst, 4 is the best)
Ho et al, 2015	Pronator teres to ECRB transfer	– 80.9° average supination gain (SD 30.7, range 30 to 155°, p < 0.05). – 76.9° average wrist extension gain (SD 15.3, range 55 to 90°, p < 0.05)	Subjective improvement in 3 basic daily living skills no validated tool.	?
FCU transfer				
Beach et al, 1991	FCU to ECRB + concomitant procedures (some involving PT)	– 43° average gain active supination. – Only Green procedure: 22° – Green + concomitant PT procedure: 76°. – 59° average increase of wrist dorsiflexion (no p-value given)	no validated tool	?
Thometz et al, 1988	FCU to ECRB + PT release in some patients (8)	?	6,5 points average improvement in the classification system of Green and Banks. (no p-value given)	?
Wolf et al, 1998	FCU to ECRB/ECRL/EDC + several other procedures (some involving PT)	Forearm rotation resting position: – 8/16 from pronation to neutral – 1/16 from pronation to supination – 7/ 16 remained in slight pronation Wrist resting position: – 3/16 from flexion to neutra – 11/16 from flexion to extension	no comparison pre vs postoperative	parents + patient: *14 of 16 felt improvement in function *16 of 16 noted improved cosmesis *14 of 16 would recommend the procedure to others *15 of 16 were satisfied overall

Table II. — Overview of outcomes, cont.

El Said, 2001	FCU to ECRB + flexor-pronator release	non quantified 'gain in mobility in forearm, wrist and hand' (no p-value given)	?	?
Mifsud et al, 2020	FCU to ECRB transfer +/- PT rerouting +/- elbow flexor releases +/- finger flexor muscle releases.	– 40.1° mean increase in active supination (p=0.002, SD 36.1) – 28.9° mean increase in active wrist extension (p=0.004, SD 29.5) – FCU to ECRB transfer only (without PT release or re-routing): mean increase in supination and wrist extension 28.6° and 30.0°	25.4% increase in DPA (part of the SHUEE): • 40.3% due to increase in wrist function • 16.8% due to forearm function (p=0.08)	?
Chibirov et al, 2020	modified FCU transfer + several other procedures (some involving PT)	mean gain in active supination (p<0.03): – 40° diplegia group – 45° hemiplegia group	Improvement in the functional class according to Van Heest classification in all patients (no p-value given)	?
Neurectomie				
Helin et al, 2018	Neurectomy of PT	42° average gain in active supination (range 0-100°, p < 0.05)	No siginificant change in functional House score.	?
Gras et al, 2017	Neurectomy of PT (subgroup of study)	– Spontaneous position improved – Reduced spasticity according to Ashworth and Tardieu scales – Active supination increased and pronation strength was unchanged CAVE no P-value	Improvement of House score (no p-value given)	for the subgroup of children: – child's satisfaction was 8.1 – parents' satisfaction was 6.5.
Puligopu et al., 2011	Neurectomy in the upper limb of children with cerebral palsy (subgroup PT)	– reduction of spasticitiy (Ashworth scale) of PT with a mean of 0,71 p<0,005) – improvement in selective voluntary control of pronation with a mean increase of 0.83 (p<0,005)	Mean increase in Wee FIM score: 4.85 (P = 0.001).	?

The PT tenotomy is a commonly used procedure, nevertheless studies examining the effect of this technique are very scarce. Strecker et al compared the results of PT tenotomy and PT rerouting[4]. Two studies examined the outcome of PT to the extensor carpi radialis longus/brevis (ECRB/ECRL) transfer, which can be considered a PT release in terms of impact on pro- and supination[14,15]. The combination of these studies yields 47 patients in total who underwent a PT tenotomy. In these studies:

– Gain of mean active supination ranged between 54,5° and 80,9°.
– Loss of mean active pronation ranged between 17 and 22° (not mentioned in study of Strecker et al).

A functional gain is also mentioned in the form of a significant increase in the upper extremity functional index (UEFI) score[15] and a functional improvement in 3 basis daily living skills[14]. However, this functional improvement may also be due to the effect of these procedures on the wrist[14,15].

C. Pronator teres rerouting

Pronator teres rerouting is described in literature to correct pronation deformity of the forearm in patients with CP[4,16]. Rerouting has a theoretical advantage relative to a release procedure of adding supination strength, by functioning as an supinator through a windlass effect.

Table III. — Overview of existing surgical techniques to correct pronation deformity. Reports on outcome of eight surgical techniques to address pronation deformity in CP patients were found in literature: these are indicated in bold.

Retrieved surgical modalities in treating pronation deformity in cerebral palsy	
Releases	•**Pronator teres release**
	• Z-lengthening or fractional lengthening of pronator teres
	• Pronator quadratus release
	• Flexor aponeurotic release – **Flexor pronator slide** - Fractional lengthening of flexor tendons
Tendon transfers	• **Pronator teres rerouting**
	• **Brachioradialis rerouting**
	• **Brachialis rerouting**
	• **Flexor carpi ulnaris to extensor carpi radialis brevis /longus (ECRB/L)**
	• **Pronator teres to ECRB/L**
Neurectomy	• **Pronator teres neurectomy**
	• Pronator quadratus neurectomy
Bony procedures	• Elbow fusion
	• Distal radio-ulnar fusion

However, a significant supinating effect of PT rerouting has not been conclusively demonstrated in cadaver and biomechanical studies[9,17,18].

Tabel IV. — Overview of loss of motion and complications/deformities.

Study	Procedure	Loss of active pronation	Complications
brachioradialis transfer			
Ozkan et al, 2004	Brachioradialis rerouting + PQ tenotomy and Z-lengthening of PT	10 to 30° (no p-value given)	No reported complications
Brachialis transfer			
Ozkan et al, 2012	Brachialis muscle transfer (+ release of PT/PQ/IO membrame)	27,5° mean (no p-value given)	No reported complications
Releases			
Thevenin et al 2013	Flexor- pronator slide.	Not reported	• 1 fixed supination • 12 persistent wrist flexion • 7 unmasked spasticity of intrinsic muscles
Strecker et al, 1988	PT tenotomy vs PT transfer	Not reported	1 supination overcorrection deformity in tenotomy group.
Release in form of PT to ECRB			
Singh et al, 2020	Pronator teres to ECRB transfer	17° mean (P< 0,05)	No reported complications
Ho et al, 2015	Pronator teres to ECRB transfer	22° average (P < 0.05).	1 supination overcorrection deformity
PT rerouting			
Bunata et al, 2006	PT rerouting	22° average (P<0,001)	• 1 supination overcorrection deformity. • 9 patients with dynamic positioning in supination
Rothe et al, 1993	PT rerouting + additional procedures	Loss reported, but not quantified	No reported complications
Cobeljic et al, 2015	Pronator teres transposition to ECRB or Pronator rerouting or Pronator rerouting with Pronator quadratus myotomy	7° average (no p-value given)	No reported complications
Neurectomie			
Helin et al, 2018	Neurectomy of PT	No loss of ROM	No reported complications
Gras et al, 2017	Neurectomy of PT (subgroup of study)	Not reported	No reported complications
Puligopu et al., 2011	Neurectomy in the upper limb of children with cerebral palsy (subgroup PT)	Not reported	No reported complications

The retrieved clinical studies in this review investigating the effect of the PT rerouting include 124 patients[4,19-21]. In these studies:

– Gain in mean supination ranged between 50-78,1°.
– There was some loss of active pronation in all (range of mean loss 7-22°).

Gain in functionality is reported after a pronator rerouting procedure by Bunata et al, Rothe et al and Cobeljic et al.[19-21]. However to assess functionality, Bunata et al used a non-validated tool and in several cases the PTR was combined with other procedures at the same surgical setting. Cobeljic et al used a tool not specific to patients with neurological disorders. Rothe mentioned a gain in House score, but the contribution of PTR in this functional gain cannot be deduced given several simultaneous procedures.

The outcomes of PT rerouting appear broadly comparable to the results of PT release. There is only one clinical study comparing the outcomes of PT tenotomy (PTT) vs PT rerouting (PTR)[4]. They concluded PTR causes a greater active supination of the forearm than PTT. However, there is great uncertainty about comparability of the groups according to ROM and function at baseline, risk of bias in the study is great and statistical significance was not checked.

D. Higly selective neurectomy (HSN)

HSN aims at re-equilibrating the tonic balance between agonist and antagonist muscles by reducing excess spasticity[22]. Decreased spasticity is obtained by sectioning both afferents and efferent fibers of the

Tabel V. — Overview of loss of motion and complications/deformities after Green transfer and additional information concerning the postoperative casting policy and preoperative tensioning of the FCU.

Study	Procedure	Loss of RO (forearm/wrist)	Complications	FCU tensioning	Postoperative casting policy
Beach et al, 1991	FCU to ECRB + concomitant procedures (some involving PT)	• Wrist ROM unchanged (no p-value) • Loss in forearm ROM not reported	• 1 supination overcorrection deformity • 1 wrist extension overcorrection deformity • 1 elbow stifness • 1 recurrence of deformity	At neutral against gravity	Not reported
Thometz et al, 1988	FCU to ECRB + PT release in some patients (8)	Not reported	• 9 dynamic wrist extension • 2 (out of the above 9): supination-extension overcorrection requiring revision surgery	At 25° wrist dorsiflexion	4-6 weeks above elbow cast: – elbow in 60° flexion – complete supination – wrist in 25° extension
Wolf et al, 1998	FCU to ECRB/ECRL/EDC + several other procedures (some involving PT)	Not reported	No reported complications	Not reported	Immobilization for the first 4 to 6 weeks, position not mentioned
El Said, 2001	FCU to ECRB + flexor-pronator release	Not reported	No reported complications	At 45° wrist dorsiflexion and forearm in full supination	5 days above-elbow plaster cast: – wrist in 45° of dorsiflexion – forearm in supination
Mifsud et al, 2020	FCU to ECRB transfer +/- PT re-routing +/- elbow flexor releases +/- finger flexor muscle releases.	Not reported	No reported complications	Not reported	Not reported
Kreulen et al, 2004	Pronator teres rerouting AND FCU transfer to ECRB	Mean loss of active pronation: 40° (P=0,011)	1 supination overcorrection deformity	With wrist in neutral or slight flexion against the force of gravity	6 weeks casting, position not mentioned
Chibirov et al, 2020	modified FCU transfer + several other procedures (some involving PT)	Not reported	No reported complications	Modified technique	Not reported

stretch-reflex at the level of a muscle's nerve. It is the only surgical technique which affect the underlying spasticity directly. It is stated in literature the HSN can be indicated for focal spasticity when there is sufficient power of the antagonists and absence of fixed contractures.

In this review, we found reported results of HSN procedure on 54 pronators in three studies[22-24]. Only one study reported the analytic gain in active supination: Helin et al reported a significant increase of 42°[22]. Gras et al reported improvement of spontaneous forearm position[23] and Puligopu et al reported a significant decrease in spasticity[24].

Reports of gain in functionality vary. Helin et al reported no significant change of the House score. Gras et al did find an increase of the House score, however (reporting of) statistical significance is missing and HSN was simultaneously executed on other muscles.

The latter was also the case in the study of Puligopu et al, who reported a significant increase in the Wee Fim score.

The active pronation was maintained in the retrieved studies. This represents a potential advantage over the other procedures, where a decrease in active pronation is often seen[10,14,15,19-21,25] or risk of overcorrection deformity is present. The explanation can be found in the mechanism of action of HSN: after 6 months motor recovery occurs because of sprouting from the remaining axons or regrowth of the cut axons. Spasticity does not reappear since the cut dendrites are unable to regrow and the sensory part of the stretch reflex remains interrupted[22].

Given these results, HSN can be indicated in a selected group of patients in which temporary blocks of motor nerves innervating the targeted muscle resulted in a good outcome.

2. Procedures for pronation deformity and wrist flexion deformity

There are three procedures described in literature that address both forearm and wrist deformities in one procedure.

The flexor-pronator slide is one of these procedures. Only one study was retrieved that examined the effect of the flexor- pronator origin slide on wrist flexion and forearm pronation. Thevenin et al reported a significant gain in wrist extension and Zancolli and House classification with this technique[13]. However, given the small number of CP patients in the study, the limited quality of the performed study, the non negligible complication rate and limited effect on pronation (only 14/19 improved to a neutral position), we do not consider this technique as an evidence based, effective technique in addressing flexion-pronation deformity in patients with cerebral palsy.

Another technique is transfer of the PT to the ECRB/ ECRL. The procedure transfers the pronation force of the PT to a vector performing wrist extension. The impact on pro-supination range is similar to a PT release, since the transfer to the ECRB/L does not add a supinating force[14,15]. This has the theoretical advantage of avoiding a possible secondary supination contracture.

The third technique is the FCU to ECRB transfer (Green transfer). This transfer has the double advantage of removing the deforming force causing ulnar deviation and wrist flexion, while promoting forearm supination and wrist extension[9,26].

The relevant articles taken together, outcome of FCU to ECRB/ECRL transfer was reported in 139 patients. The gain in mean active supination ranged between 22° and 63° in these studies[5,27-30]. Mean gain in wrist dorsiflexion ranged from 28,9° to 59°.

FCU transfer was often combined with surgery to the PT in the retrieved studies. Of 34 patients who had exclusively undergone a Green transfer to augment supination, the results were reported separately[5,30]: the gain in mean active supination ranged between 22° and 28,6° in this group.

Regarding gain in functionality after a Green procedure, Mifsud et al reported a significant increase in the dynamic positional analysis (part of the Shriners Hospital Upper Extremity Evaluation (SHUEE)) of 25.4%: 40.3% due to increase in wrist function and 16.8% due to forearm function[30]. In some patients however there was simultaneous surgery on the PT. Beach et al also reported gain of function postoperatively, however they used a subjective, non- validated tool[5]. Thometz et al reported average improvement of 6,5 points according to the classification system of Green and Banks[27]. (Reporting of) statistical significance was missing and some patients had simultaneous surgery to the PT.

These results seem comparable to results of the PT to ECRB transfer: the mean gain of wrist flexion in the studies on PT to ECRB transfer ranged from 15° to 76,9°. Moreover, supination gain appears similar or greater in PT to ECRB compared to the Green transfer[14,15] and some authors state that the supination effect of only a Green transfer is too small to address more severe pronation deformities and additional surgery on the PT is required[29] Indeed, in the retrieved studies the gain in supination was clearly greater in patients who underwent Green transfer and PT surgery than in patients with Green transfer alone[5,30]. As a consequence, one might argue to go for PT to ECRB transfer in patients with flexion- pronation deformity instead of the more commonly used Green transfer. However, Bisneto et al (study not included due to exclusive focus on the wrist) analysed data on 37 CP patients after transfer of the PT or FCU to the ECRB/L[31]. They concluded that maximum active wrist extension is significant greater in the FCU transfer group, compared to the PT transfer group. Moreover, the studies in this review on PT to ECRB transfer only included patients who had complete passive supination and the majority of patients were hemiplegic. As a result, their results cannot be generalized to the entire target group of this review.

3. Complications

An important element to consider is the risk of complications of the variant techniques, including the development of an overcorrection deformity. According to some authors, a supination deformity (inability to actively pronate the forearm past neutral) is an even greater handicap than a pronation deformity, particularly in wheelchair bound patients[16].

Altogether, 2 (out of 47) patients with PT tenotomy had a supination overcorrection deformity, compared to 1 out of 124 patients in the PT rerouting group.

Both Ho et al (PT release) and Bunata et al (PT rerouting) stated that the risk of overcorrection is greater when preoperative pronation spasticity/contracture is greater and active supination preoperative is smaller[14,19].

An overcorrection deformity can also occur after performing a Green transfer. Both a supination deformity and a wrist extension deformity can develop. With wrist overcorrection deformity included, 5 out of 139 patients (4%) who underwent a green transfer developed an overcorrection deformity.

Kreulen et al warn that the risk of pronation loss and overcorrection deformity is greater when combining the Green procedure and a procedure to the PT [25]. In 74 of

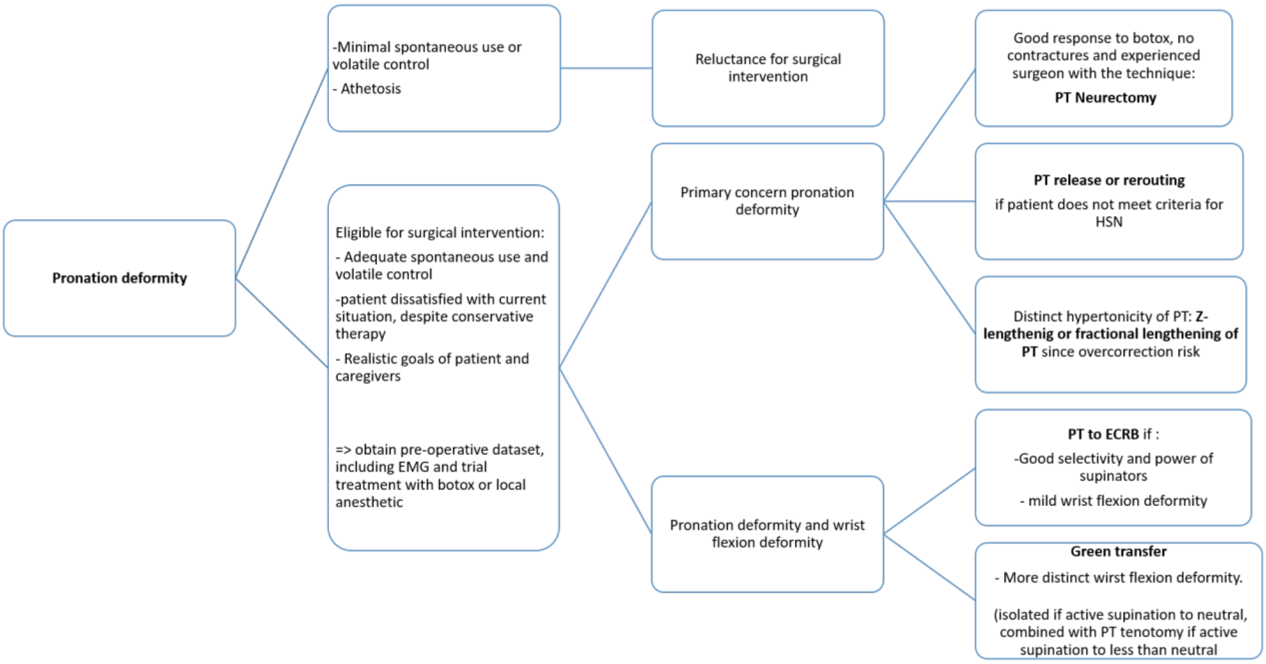

Fig. 2 — Proposed surgical treatment flowchart.

the patients in the retrieved studies simultaneous FCU to ECRB and surgery to the PT was performed[5,25,28]. One out of the 74 patients had a supination overcorrection deformity postoperative, compared to 4 out of 139 in the total group who underwent FCU transfer. Based on the findings in this review, the combination of the Green transfer and surgery to the PT does not seem to significantly increase the risk of an overcorrection deformity.

Several other factors can influence the development of overcorrection deformities.

Beach et al considered the postoperative casting policy as the main factor in developing an overcorrection deformity[5]. Another possible factor influencing the development of overcorrection deformities is the tension of the FCU tendon when attaching it to the ECRB. This tension varies in the retrieved studies between neutral position of the wrist and 45° dorsiflexion. Tensioning the tendon to neutral against gravity seems a safe and efficient tensioning regime[5,25].

An overview of loss of motion, complications and overcorrections can be found in table IV and V. In the group of articles addressing the Green transfer, additional information concerning the postoperatieve casting policy and peroperative tensioning of the FCU can be found in the table, as it has possible relevance in development of overcorrection deformities.

Developing an evidence based guideline to guide clinical practice

There is a need for a well-defined subdivision of patients with CP and pronation deformity with associated evidence based therapeutic consequences.

A classification for pronation deformity and a proposed treatment plan were published in 1992 and updated in 2003 by Gswind et al[7,16]. However this plan was derived more from experience than being evidence based and the result of this review provide no evidence to support this treatment plan.

Comparing the outcome of all the techniques utilised is difficult, mainly due to the very large heterogeneity of reported outcome parameters, characteristics of the included patients and quality/methodology of the retrieved studies. A challenge of any study that evaluates patients with CP is that the extent of deformity and limb involvement varies, which makes it difficult to compare patients within a study as well as between studies[32].

Moreover, in the reporting within the articles of this review, too little attention is given to subgroup analysis (concerning preoperative active rom, type of cp, intelligence, age), which could determine factors influencing the surgical outcome.

The elements above unfortunately prohibits making evidence based recommendations to guide clinical practice at this time. However, this review can help to make a well-considered plan based on the patient's goals and expectations, which can vary between functional gain or improvement of aesthetic aspect or hygienic concerns.

Based on the findings in this review, a start to such a guideline was drawn up (cfr figure 2). The flowchart gives an overview of the surgical options, without being an evidence based guideline.

In the future, to enhance the comparability of studies and to enable pooled analysis, a uniform pre- and postoperative dataset should be collected in all studies including certainly but not only: type of cerebral palsy, GMFCS scale, Spasticity scale, ROM (Ideally using a three-dimensional video analysis[33]), defined goals of surgery, postoperative policy and most important pre- and postoperative functionality. For the latter we agree with the suggestion of Louwers et al, who conducted a systematic review on effect of upper limb surgery on activities and participation of children with cerebral palsy, to add at least these three validated activity-based outcome measures to the core dataset: the AHA, SHUEE, and COPM.[34,35,36].

Using this kind of a uniform pre- and postoperative dataset, it might be possible to retain evidence based selection criteria for surgery, to indicate specific surgical procedures and to predict outcomes in a specific patient.

Limitations

The greatest limitation of this study is the focus on only the pronation deformity. Even though it represents one of the more visible abnormalities with potentially major impact on upper limb functionality, it rarely is an isolated condition. Surgical procedure to address pronation deformity are ideally part of single-event, multi-level surgery, in which multiple problems are addressed[37]. Isolated focus on the surgery for pronation deformity can however help to understand the dynamics of the deformity and give an insight in the specific treatment, the outcome and possible complications.

CONCLUSION

Despite positive reports on gain in supination and functionality after most procedures addressing pronation deformity in CP patients, no conclusions can be drawn concerning the preferred technique due to the low quality of the evidence. Developing an evidence based treatment guideline is not possible using the current evidence. Large, high quality studies, using a fixed, validated dataset pre- and postoperative are required to gather sufficient evidence to be able to direct therapy.

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