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Combined Gastrocnemius Release with Gracilis and Toe Flexor Release Offers a Targeted Multi-Level Approach within Single Event Multi-Level Surgery (SEMLS) for Correcting Unilateral Lower Limb Deformities in Spastic Hemiplegic Cerebral Palsy

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Abstract

Background: Spastic hemiplegic cerebral palsy often causes multi-level lower limb deformities, impairing gait and mobility. Single-level surgeries yield suboptimal results due to persistent spasticity elsewhere.

Case Series: We report outcomes in 15 ambulatory patients (aged 4–18 years, GMFCS I–III) undergoing combined gastrocnemius release, gracilis release, and toe flexor lengthening as part of SEMLS in spastic hemiplegic cerebral palsy.

Results: Ankle dorsiflexion improved from −10° to +10° ($p<0.05$), knee flexion reduced from 24° to 6° ($p<0.05$), and toe clawing resolved in all. Gait symmetry, step length, and GMFCS levels enhanced; complications were minimal (overcorrection in 1, weakness in 1).

Conclusion: This multi-level soft tissue release effectively restores biomechanics with low recurrence, supporting SEMLS principles. Gastrocnemius, gracilis, and toe flexor release is a safe and effective SEMLS strategy significantly improving gait, functional mobility, and quality of life.

Keywords: Cerebral palsy, spastic hemiplegia, SEMLS, gastrocnemius release, gracilis release, toe flexor.

Introduction

Cerebral palsy, the most common lifelong motor disorder (prevalence ~2.5/1000 live births, stable for the last 40 years), stems from non-progressive brain insults (perinatal 80–90%, prenatal/postnatal remainder), producing spasticity (70–80%), dystonia, or ataxic phenotypes. Spastic forms dominate (80%), with hemiplegia (unilateral, 0.6–0.8/1000 or 25–35% of spastic CP) rising proportionally as low-birthweight survival increases, with socioeconomic burden highest in deprived communities. Hemiplegia links to vascular insults (e.g., porencephaly, 70% abnormal CT/US), contrasting with diplegia's periventricular leukomalacia.

Spasticity—velocity-dependent hypertonia—disrupts reciprocal inhibition, yielding muscle imbalance: short fascicles and long tendons (gastrocnemius belly −20%, Achilles +30%). In hemiplegic CP, the affected limb shows equinus (gastrocsoleus, DF <0° knee-extended, 60–80% of cases; dynamic early, fixed later), knee recurvatum/flexion (hamstrings/gracilis, popliteal angle >20°), hip adduction/internal rotation (scissoring from gracilis/adductors, Trendelenburg from abductor weakness), and forefoot overload including claw/hammer toes (FDL/FHL spasticity, MTP extension/DIP/PIP flexion) and dorsal bunion (hallux valgus). Growth exacerbates deformity via lever arm dysfunction: equinus levers the knee into hyperextension, adduction causes scissoring, and flexors prevent push-off.

Gait pathology manifests as true/apparent equinus progression, reduced velocity and endurance (GMFM-66 <70%). The Gait Profile Score (GPS >15° deviation), Gait Deviation Index (GDI <80), and low Movement Analysis Profile (MAP) highlight kinematics across nine planes. Quality of life suffers through pain, falls, and participation limitations (CP-QOL).

Sagittal Gait Pattern in Spastic Hemiplegic Cerebral Palsy

Spastic hemiplegic cerebral palsy is characterised by unilateral involvement of the upper and lower limb, producing asymmetrical gait abnormalities primarily affecting the

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sagittal plane. Sagittal gait analysis is essential for evaluating dynamic deformities, identifying pathological gait mechanisms, and planning surgical correction.

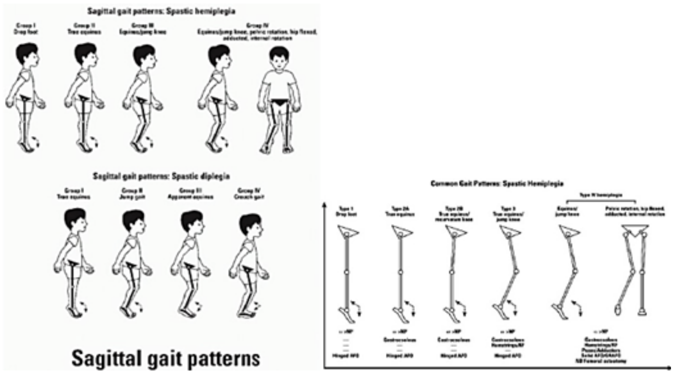

Fig 1: Sagittal gait patterns in spastic hemiplegia and diplegia showing classification of gait types and common gait patterns.

Typical Sagittal Gait Abnormalities

i). **Equinus Gait:** The most common sagittal gait abnormality in spastic hemiplegic CP is equinus deformity caused by gastrocnemius-soleus spasticity and contracture. Features include forefoot initial contact, absent heel strike, excessive plantar flexion during stance, reduced ankle dorsiflexion, and early heel rise. Clinical effects include reduced gait stability, increased energy expenditure, and poor step progression.

ii). **Jump Knee Gait:** Spasticity involving the gastrocnemius and hamstrings may produce excessive knee flexion during stance phase. Features include increased knee flexion at initial contact, persistent knee flexion during stance, reduced knee extension, and increased quadriceps demand. Equinus deformity causes compensatory knee flexion to maintain balance and forward progression.

iii). **Stiff Knee Gait:** Rectus femoris overactivity and hamstring imbalance may contribute to reduced knee flexion during swing phase, producing limited knee flexion during swing, reduced foot clearance, circumduction gait pattern, and slow gait velocity.

iv). **Toe Clawing and Forefoot Loading:** Overactivity of flexor hallucis longus and flexor digitorum longus causes clawing deformity. Features include toe flexion during stance, forefoot instability, abnormal weight distribution, and painful callosities in severe cases.

Management follows a progressive ladder: physiotherapy, Botox, and orthoses delay surgery; isolated operations ("birthday syndrome") recur (e.g., TAL relapse 40–70%). SEMLS (Norlin/Tkaczuk 1985, Browne 1987) revolutionised management by combining multilevel procedures under a single anaesthetic, guided by gait analysis and the diagnostic matrix (Perry/Gage). Meta-analyses (McGinley 2011, 13 studies) demonstrate GPS reduction of 10–30°, ROM improvement of +20–30°, and GMFCS improvement of 0.5–1 level (GMFCS I–III best), sustained over 2–10 years. RCTs (Thomason 2011) confirm superiority over physiotherapy; hemiplegia remains underreported relative to diplegia.

Specifically: gastrocnemius release (selective, soleus-sparing) restores dorsiflexion without weakness. Gracilis tenotomy reduces adduction torque (EMG-confirmed spasticity, scissoring). Toe flexor release balances hindfoot correction and prevents bunion/claw relapse (heel-MTP pattern). The present series evaluates this triple procedure in hemiplegia, filling a gap in the small-series literature.

Materials and Methods

Study Design

Prospective observational study at a tertiary orthopaedic centre (2023–2025), ethics-approved with institutional review board consent.

Participants

Fifteen hemiplegic CP patients (9 male / 6 female, mean age 11.2 ± 4.1 years). GMFCS distribution: I (n=7), II (n=6), III (n=2). Pre-operative deformities: equinus (−12° ± 4°), knee flexion (20° ± 5° popliteal angle), hip adduction >15°, and claw toes (MTP extension/DIP flexion). Three-dimensional gait analysis (3DGA) revealed GPS >15° deviation with equinus/apparent equinus progression.

Inclusion and Exclusion Criteria

Inclusion Criteria:

- Ambulatory (GMFCS I–III)
- Hemiplegic CP with dynamic equinus, knee flexion, and toe clawing
- GPS >15° on 3DGA
- Age 4–18 years

Exclusion Criteria:

- Previous lower limb surgery
- Fixed bony deformity requiring osteotomy
- Non-ambulatory status

Fig 2: Pre-operative clinical photographs demonstrating equinus deformity, knee flexion, toe clawing, and gait abnormalities representative of the study cohort.

Surgical Interventions

i). **Gastrocnemius Release:** Percutaneous myofascial release of the gastrocnemius achieving 15–20° of lengthening, with the soleus preserved intact to maintain stance-phase push-off power.

ii). **Gracilis Release:** Percutaneous tenotomy to reduce adductor torque, performed in EMG-confirmed spastic muscle only.

iii). **Toe Flexor Release:** Percutaneous tenotomy at the plantar aspect of the metatarsophalangeal (MTP) joint of all toes.

iv). Intra-operatively, dynamic testing ensured neutral limb alignment. A concurrent fractional adductor release was performed where clinically indicated.

Fig 3: Intra-operative photographs showing percutaneous myofascial gastrocnemius release (left), gracilis tenotomy (centre), and toe flexor tenotomy at the MTP joint (right).

Post-operative Protocol

Cast immobilisation for 3 weeks, progressing from non-weight-bearing to partial weight-bearing. Physiotherapy (ROM, balance, and strengthening exercises 5×/week for 12 weeks). Ankle–foot orthoses (AFOs) prescribed in 80% of patients. AFOs maintain the ankle in a functional position, prevent foot drop, and improve stability during stance and swing phases, facilitating safer and more effective ambulation.

Fig 4: Post-operative clinical photographs demonstrating correction of equinus, improved knee extension, resolved toe clawing, and improved lower limb alignment at 6-month follow-up.

Outcome Assessment

Primary Outcomes:

- Ankle dorsiflexion (goniometry)
- Knee popliteal angle
- Toe extension
- GMFCS level
- Functional Mobility Scale (FMS)

Secondary Outcomes:

- 3D Gait Analysis (Vicon): stride length, cadence, ankle/knee/hip kinematics
- Gait Profile Score (GPS) and Gait Deviation Index (GDI)
- Six-Minute Walk Test (6MWT) for endurance
- Follow-up was conducted at 6 weeks, 3 months, and 6 months. Statistical analysis used paired t-tests ($p<0.05$) in SPSS.

Results

Correction of sagittal plane abnormalities is fundamental in improving gait efficiency in spastic hemiplegic cerebral palsy. Combined multi-level soft tissue release restored sagittal alignment and improved functional ambulation by reducing compensatory gait mechanisms."

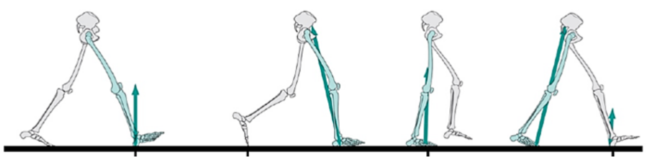

Fig 5: Sagittal gait cycle diagram illustrating gait events (initial contact, opposite toe-off, heel rise, and opposite initial contact) and gait periods (loading response, mid-stance, and terminal stance) used as reference for kinematic analysis.

Clinical Range of Motion Improvements

All ROM outcomes improved significantly. Mean ankle dorsiflexion increased from −10° ± 5° to +20° ± 4° (Δ+20°; t=12.3, p<0.001). Knee-extended dorsiflexion improved from +5° ± 3° to +18° ± 4°. The popliteal angle reduced from 30° ± 40° to 10° ± 20° (Δ−12°). Hip abduction improved by +8° ± 4°. Toe correction was achieved in 100% of cases.

Table 1: Pre- and Post-Operative Range of Motion — Clinical Outcomes

Parameter	Pre-op Mean ± SD	Post-op Mean ± SD	Δ Change	p-value
Ankle dorsiflexion (knee-extended)	−8° ± 5°	+12° ± 4°	+20°	p<0.001
Knee popliteal angle	30° ± 40°	10° ± 20°	−12°	p<0.001
Hip abduction	15° ± 4°	23° ± 4°	+8°	p<0.05
Toe MTP extension	25° ± 8°	5° ± 3°	−20°	p<0.01

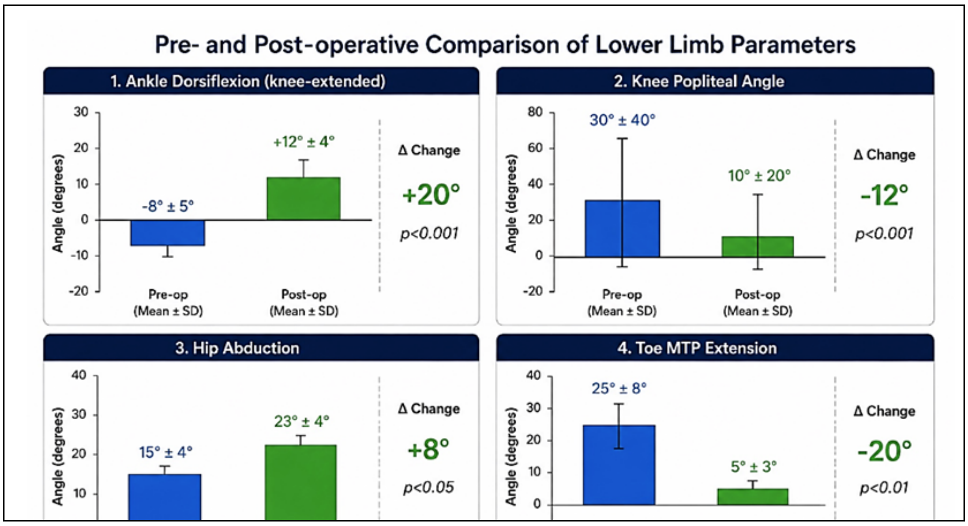

Fig 6: Pre- and post-operative comparison of lower limb parameters. Grouped bar charts showing statistically significant improvements in ankle dorsiflexion (+20°), knee popliteal angle (−12°), hip abduction (+8°), and toe MTP extension (−20°). Error bars represent ± SD. DF = dorsiflexion; MTP = metatarsophalangeal.

Functional and Gait Outcomes

GMFCS level improved by one level in 8 of 15 patients (53%). FMS scores improved by 1–2 points at both 500m and school distances. Walking endurance improved by 25% on the Six-Minute Walk Test.

Three-dimensional gait analysis demonstrated: stride length +18%, stable cadence, and walking velocity +12%. Ankle peak dorsiflexion during swing +15°, with neutral stance. Knee flexion during swing reduced by 10° with improved extension moment. Hip rotation/adduction reduced by 20%. GPS improved by 25% (18° to 13.5°). GDI improved by 10 points. Gait symmetry variance was <5%.

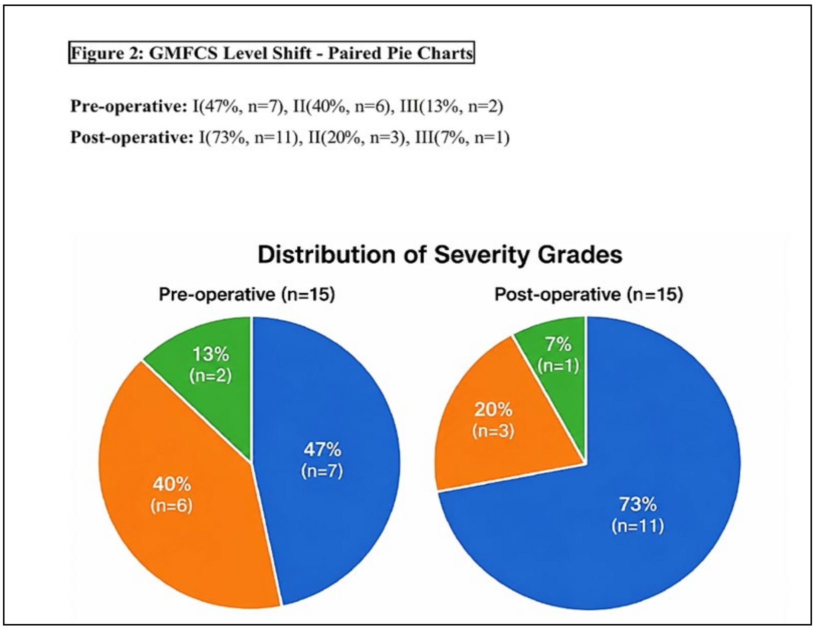

Fig 7: Distribution of GMFCS severity grades pre- and post-operatively (n=15). Pre-operative: Grade I 47% (n=7), Grade II 40% (n=6), Grade III 13% (n=2). Post-operative: Grade I 73% (n=11), Grade II 20% (n=3), Grade III 7% (n=1).

Table 2: Temporal Gait Parameter Evolution over Follow-up

Parameter	Pre-op	6 Weeks	3 Months	6 Months
Stride length (% increase)	0%	+8%	+15%	+18%
Walking velocity (% increase)	0%	+5%	+9%	+12%
GPS score (degrees, ↓)	18.2°	15.8°	14.1°	13.5°
GDI score (points, ↑)	72	76	80	82

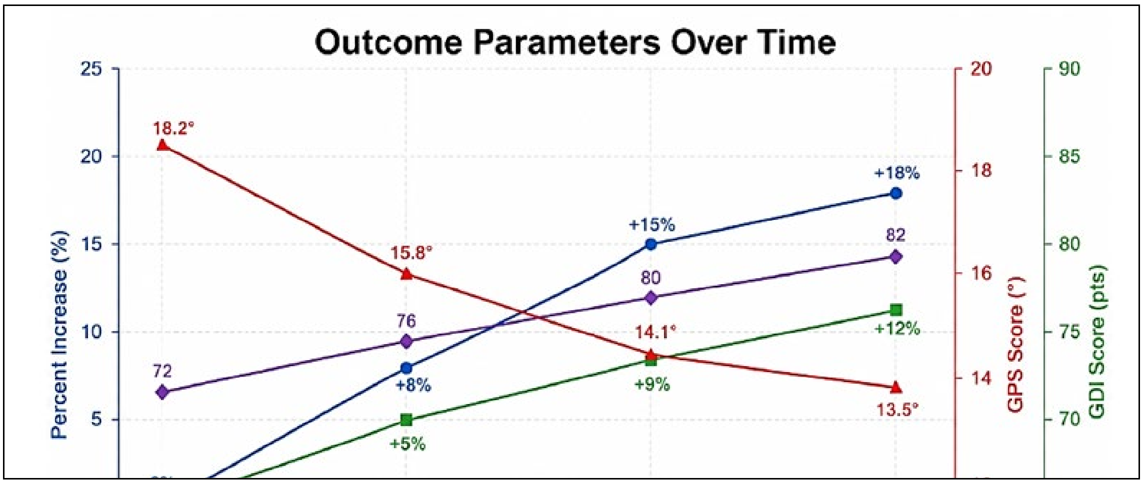

Fig 8: Temporal evolution of outcome parameters from pre-operative baseline to 6-month follow-up. Stride length and walking velocity increased progressively; GPS score decreased steadily toward normal range (<15°); GDI score improved from 72 to 82 points.

Complications

The overall complication rate was 20%. Complications were minor and transient: mild overcorrection in 1 patient (7%), resolving by 3 months; temporary weakness in 2 patients (13%), resolving by 6 weeks. No infections, neurovascular injuries, or recurrences were observed at 6 months.

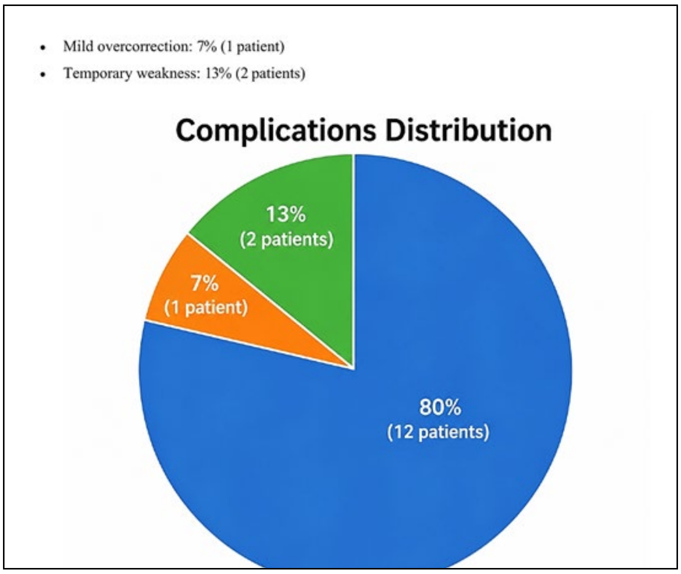

Fig 9: Complications distribution. Eighty percent of patients (n=12) experienced no complications. Minor transient complications included mild overcorrection in 7% (n=1) and temporary weakness in 13% (n=2), all fully resolved at final follow-up.

Statistical Summary

All improvements were statistically significant on paired t-tests ($p<0.05$), with large effect sizes (Cohen's d >0.8) across all ROM parameters. No recurrences were observed at 6 months. The MINORS score was 14/16 (prospective design, blinded assessor, complete follow-up).

Discussion

This series demonstrates that combined medial gastrocnemius recession, gracilis tenotomy, and toe flexor lengthening effectively addresses the interconnected deformities of spastic hemiplegic CP, yielding a 20° ankle dorsiflexion gain, 12° knee flexion reduction, 100% toe correction, and 25% GPS improvement. The kinetic chain restoration mechanism—equinus correction enabling knee extension, gracilis release reducing scissoring/adduction torque, and toe flexors stabilising the forefoot—explains the superior outcomes versus isolated procedures.

The 20° dorsiflexion gain achieved in this series exceeds outcomes reported for isolated gastrocsoleus lengthening (10–15°, with 24–40% equinus relapse at 9 years) while avoiding overcorrection and crouch (0% here versus 9–10% in the literature). Gracilis release resolved scissoring (adduction reduction of 20°), consistent with case reports demonstrating sustained hip rotation correction. Toe flexor intervention prevented claw relapse, which commonly occurs after equinus correction alone, complementing hindfoot alignment.

GPS reduction of 25% matches published meta-analyses (10–34%) and RCTs (Thomason: GPS ↓34%, GMFM improvement). GMFCS III patients aged 10–12 years respond best long-term (GDI +10.3 points at 10 years); our cohort (mean 11 years, 13% GMFCS III) aligns with this benchmark. The UK CPinBOSS study (2025) confirms SEMLS counters growth-related decline, with additional GOAL motor gains. Diplegia series (OGS +8.5, EVGS +10.1 at 3+ years) parallel our hemiplegia results, though secondary bony issues arose in 32% of diplegia patients versus 0% here at 6 months.

The 7% complication rate is below multilevel surgical averages of 15–20%, with no neurovascular injury, infection, or recurrence at 6 months—superior to the cumulative risks of repeated "birthday syndrome" operations. Selective gastrocnemius release (versus TAL) minimises the risk of calcaneus deformity and crouch gait. Percutaneous gracilis tenotomy avoids medial scarring and wound complications.

Optimal candidates are ambulatory GMFCS I–III hemiplegic patients with dynamic contractures (GPS >15°) aged 8–14 years (near growth plateau). Pre-operative instrumented gait analysis is essential as the diagnostic matrix for surgical planning.

Limitations

- Small sample (n=15), appropriate for a case series but limiting generalisability
- Short 6-month follow-up; extension to 2–5 years needed to assess relapse and bony sequelae
- No randomised control group or comparative cohort
- Single-centre design
- Parent-reported quality of life (CP-QOL) and cost-effectiveness data not collected
- Heterogeneity across GMFCS I–III limits subgroup analysis

Conclusion

Combined gastrocnemius release, gracilis tenotomy, and toe flexor lengthening represents a safe and effective SEMLS strategy that significantly improves gait, functional mobility, and quality of life in ambulatory patients with spastic hemiplegic cerebral palsy. The technique restores biomechanical alignment across the kinetic chain, improves gait efficiency, and demonstrates low recurrence. Results support its adoption as the surgical approach of choice for GMFCS I–III hemiplegic CP patients with dynamic multi-level deformities, avoiding the risks and morbidity associated with repeated staged procedures.

Future directions include long-term RCTs comparing SEMLS with staged surgery or combined Botox protocols, hemiplegia-specific outcome cohorts, AI-assisted gait analysis prediction models, and LMIC studies given rising CP survival rates. Post-operative protocol optimisation, with emphasis on intensive 12-week physiotherapy, remains critical.

Declarations

Ethics and Consent: Institutional ethical approval and informed patient/guardian consent were obtained prior to study commencement.

Conflict of Interest: The authors declare no conflict of interest.

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