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An Overview about One Session (Single-Event) Multilevel Surgery (SEMLS) for Orthopedic Surgeries for Cerebral Palsy Management

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Abstract: To effectively treat individuals with Cerebral Palsy (CP) through orthopedic surgery, the medical and rehabilitation team should possess a deep understanding of normal anatomy, particularly related to ambulation, as well as the functional pathology specific to CP. Establishing realistic treatment goals that are mutually agreed upon by the patient, family, and other stakeholders is crucial. The team must also have the knowledge and skills to perform necessary treatments, along with access to facilities equipped for evaluations and treatments. The approach to orthopedic surgery in CP has evolved towards single-event multilevel surgery (SEMLS) over the last two decades. SEMLS aims to correct all fixed musculoskeletal deformities in a single procedure, enhancing sagittal plane balance, reducing hospitalizations, and streamlining rehabilitation. This method is cost-effective, minimizes disruption to schooling, and eliminates the need for staged surgeries, which were previously common. The core principle of SEMLS is the simultaneous correction of multilevel deformities contributing to gait dysfunction in ambulatory CP patients

Keywords: *One Session (Single-Event) Multilevel Surgery (SEMLS), Cerebral Palsy*

Introduction

One Session (Single-Event) Multilevel Surgery (SEMLS) Requirements for Orthopedic Surgery in Cerebral Palsy

To effectively treat individuals with Cerebral Palsy (CP) through orthopedic surgery, the medical and rehabilitation team should possess a deep understanding of normal anatomy, particularly related to ambulation, as well as the functional pathology specific to CP. Establishing realistic treatment goals that are mutually agreed upon by the patient, family, and other stakeholders is crucial. The team must also have the knowledge and skills to perform necessary treatments, along with access to facilities equipped for evaluations and treatments [1].

Staging of Orthopedic Surgery

The approach to orthopedic surgery in CP has evolved towards single-event multilevel surgery (SEMLS) over the last two decades. SEMLS aims to correct all fixed musculoskeletal deformities in a single procedure, enhancing sagittal plane balance, reducing hospitalizations, and streamlining rehabilitation. This method is

cost-effective, minimizes disruption to schooling, and eliminates the need for staged surgeries, which were previously common [2].

The core principle of SEMLS is the simultaneous correction of multilevel deformities contributing to gait dysfunction in ambulatory CP patients [3].

Construction of a Problem List

The construction of a problem list for orthopedic surgery in CP involves synthesizing all available data, focusing on contracted muscles, joints, and osseous deformities using a diagnostic matrix concept [4].

Examination under anesthesia is essential to differentiate dynamic and fixed contractures in hypertonic muscles and joints [5]. The treatment plan also considers underlying neurological deficits to ensure comprehensive care [5].

Goals of SEMLS

Goals depend on the severity of the disease, functional impairment, and level of ambulation (Gross Motor Function Classification System [GMFCS] Level) and the goals of the person with CP, their family, and the multidisciplinary team. In the first decade of life, the most important priority for individuals with CP is function. In the second decade, it shifts to appearance, and in the third and subsequent decades, the focus becomes the avoidance of pain [6]. SEMLS should be goal-oriented and focus on projected outcomes and quality of life [6].

The general goals are to:

- Reduce spasticity in a selective manner because an increased muscle tone can sometimes be useful.
- Correct contractures that hinder function or interfere with hygiene.
- Simplify the control system.
- Preserve power generators, especially the Achilles tendon, as it is the main power generator for walking [6].

Goals of Treatment for Ambulatory Cerebral Palsy (GMFCS Levels I-III)

The goals of treatment for ambulatory individuals with CP are:

1. **Optimize gait efficiency (correct biomechanics) to optimize energy conservation:**
    - **Preserve or improve physical function:** Walk longer distances, walk faster, decrease fatigue, improve stability (reduced tripping and fewer falls), keep up with peers.
    - **Pain relief or pain prevention and increased endurance.**
    - **Preserve or increase activities and participation:** Be more physically active, achieve greater independence, participate more in sports and recreational activities.
2. **Improve the appearance of gait:**
    - **Reduced reliance on walking aids.**
    - **Reduced use of orthotics.**
    - **Feet flat on the ground.**
    - **Feet pointing forward.**
    - **Reduced dragging of feet.**
    - **More symmetry.**
    - **Stand and walk taller (knees less bent).** [7]

Goals of Treatment for Non-Ambulatory Cerebral Palsy (GMFCS Levels IV-V)

The goals of treatment for non-ambulatory individuals with CP are:

- **Relieve or prevent pain and discomfort.**
- **Facilitate ease of care:** Dressing, toileting, bathing/hygiene; positioning (seating and lying down); transfers and mobility.
- **Preserve or improve health and improve quality of life.** [7]

Lower Extremity Surgical Procedures

Lower extremity surgical procedures can be divided into musculotendinous surgery, tendon transfers, and osteotomies.

Main Indications for Soft Tissue Release Surgery

- **Hip adductor lengthening:** Indicated in the presence of dynamic hip adduction in combination with static tightness of the hip adductors. Generally, when children have 20 degrees or less of hip abduction with the hip extended.
- **Psoas recession:** Psoas tightness typically results in the inability to get the affected limb into a trailing position. The main indication for psoas recession is excessive hip flexion in terminal stance in patients with at least a 10-degree flexion contracture on static examination.
- **Hamstring lengthening:** Typically indicated for children with excessive knee flexion in terminal swing and stance and with popliteal angles greater than 40 degrees.
- **Achilles tendon lengthening:** Indicated in moderate to severe ankle equinus deformity with achilis tendon contracture.
- **Gastrocnemius recession:** Usually indicated in Achilles tendon contracture with weak triceps surae [8].

Lower Extremity Soft Tissue Procedures in Cerebral Palsy

A prospective cohort study on the effects of lower extremity soft tissue surgery in ambulatory patients revealed a significant improvement in function and quality of life for the surgically treated patients compared with nonsurgically treated patients [9].

1. Hip Problems

Non-ambulatory individuals with severe spasticity (GMFCS IV-V), adduction contractures, and pelvic obliquity face an elevated risk of hip subluxation and dislocation. Acetabular dysplasia typically occurs in the posterolateral region or may be global in nature. The primary aim of treatment is to preserve mobile and well-positioned hips.

While many experts advocate for surgical interventions to sustain hip reduction, the lasting implications of hip dislocation in adults with cerebral palsy remain uncertain [10].

Early diagnosis is crucial to achieve this goal, and close clinical and radiographic follow-up at periodic intervals is imperative in patients with clinical risk characterized by progressive spasticity and adduction deformity, with less than 30 degrees of passive hip abduction. In children with moderate subluxation radiographically (30-50% migration percentage) but with decreased range of motion (hip at risk), early adductor release and hip flexor lengthening are indicated [11].

Goals of Treatment:

- Prevent hip subluxation and dislocation.
- Maintain comfortable seating.
- Facilitate care and hygiene.
- Maintain >45 degrees of hip abduction after releases [11].

Adduction contracture may result in scissoring in ambulatory or progressive hip subluxation in non-ambulatory children. Surgical management consists of myotomy of the adductor longus. Obturator neurectomy is contraindicated because it may result in postoperative abduction contracture. Hip flexion contracture is associated with anterior pelvic tilt, increased lumbar lordosis, and crouched gait. To preserve strength of hip flexors, iliopsoas tendinous recession at the pelvic brim is traditionally recommended. However, according to a previous study in ambulatory patients with spastic diplegia, the improvement in hip extension was greater when following iliopsoas complete tenotomy at the lesser trochanter without any adverse effect [12].

2. Knee Problems

Ambulatory children with diplegic or quadriplegic CP frequently develop a crouched gait secondary to tight hamstrings and knee flexion contractures. In such cases, hamstring lengthening, with or without extension casting, is the treatment of choice. Semitendinosus and gracilis muscles are Z-lengthened, while the semimembranosus undergoes tendinous recession, which is known as fractional lengthening [13].

Complications include sciatic nerve injury, genu recurvatum (more likely when medial and lateral hamstrings are lengthened), stiff knee gait in cases of contraction of the rectus femoris, and increased anterior pelvic tilt in cases of iliopsoas cospasticity.

According to a recent study, soft-tissue surgery in ambulatory children with CP significantly improves static knee contractures and knee kinematics [14].

3. Ankle and Foot Problems

Equinus deformity is the result of contracture of the gastrocnemius or both the gastrocnemius and the soleus. Surgical lengthening is indicated if initial non-operative management is ineffective. Preoperative evaluation of a patient with perceived equinus gait should include assessment of hamstring spasticity [14]. Crouched gait secondary to over-lengthening of the gastrocsoleus complex may complicate treatment in this population of patients with CP [15].

Surgical alternatives include selective gastrocnemius tendinous recession, open or percutaneous sliding technique, and Achilles tendon Z-lengthening. Selective recession of the gastrocnemius is preferred to Achilles tendon lengthening because it preserves power for push-off and is less likely to result in over-lengthening and subsequent crouched gait. Recurrence is not uncommon and is more likely to occur in diplegic patients younger than 4 years of age and patients who undergo gastrocnemius recession [16].

Preoperative Evaluation

Patients should be evaluated for the following:

1. **History taking:** Emphasize on, but not limited to: perinatal history, developmental history, any recent deterioration of patient activities and anterior knee pain, previous physiotherapy, and previous interventions.
2. **Clinical examination:** Standard couch examination of each patient; goniometric measurements of joint ROM and deformities for the hip, knee, and ankle joints bilaterally; muscle power of the lower limb muscles assessed on a five-grade scale by manual muscle testing; and observational gait analysis.
3. **Documentation of failure of non-operative management.**
4. **Evaluation of gross motor function classification system (GMFCS) for children with CP.**
5. **Spasticity score according to modified Ashworth scale [17].**

Preoperative Preparation

1. **Describing accepted indications and contraindications for surgical intervention.**
2. **Identifying medical co-morbidities that might impact surgical treatment.**
3. **Ordering appropriate initial laboratory studies.**
4. **Obtaining operative consent:**
    - Describe the steps of the procedure to the attending prior to the start of the case.
    - Describe potential complications and steps to avoid them.
5. **Room preparation:**
    - Standard OR table.
    - Right angle clamp.
    - Right angle retractors (e.g. Sofield or Army-Navy)
    - Tourniquet [17].

Techniques

(1) Hip Adductor Lengthening

Hip adductor lengthening may be performed either open or percutaneously.

Percutaneous technique:

1. Hip positioned in 90 degrees flexion and abduction.
2. A no.15 Blade placed anterior to adductor longus tendon at the level of the groin crease without cutting.
3. Blade used to "drag" skin posterior to the tendon to be parallel to the floor and directed cephalad.
4. Blade inserted fully and turned 90 degrees.

5. Blade swept anteriorly while the surgeon pushes the tendon against it to facilitate dividing the tendon [18].

Open technique:

1. Patient is positioned supine.
2. Make a 3-4 cm transverse incision in the proximal groin crease.
3. Dissect through the subcutaneous tissue using bovie electrocautery, then incise the fascia in line with the skin incision.
4. Identify the adductor longus tendon by palpation - it is usually the tightest tendon.
5. Isolate the adductor longus tendon by separating it from the surrounding tissue with a clamp and/or finger.
6. Perform a tenotomy (surgical division) of the adductor longus using electrocautery.
7. Avoid performing an obturator neurectomy due to the risk of overcorrection and fixed abduction.
8. Identify and isolate the gracilis tendon by abducting the hip and extending the knee.
9. Perform a tenotomy of the gracilis muscle as proximal as possible using electrocautery.
10. Close the fascia if possible, then close the subcutaneous layer and skin.
11. Immobilize the patient in an A-frame cast with 25-30 degrees of abduction for 3-4 weeks.
12. Manage postoperatively with diet advancement, pain control, and wound care.
13. Discharge the patient on pain control and schedule follow-up in 2 weeks [11].

(2) Psoas Lengthening

Key steps for this surgical procedure:

1. Position the patient supine with a bump under the ipsilateral hip to elevate it (in unilateral cases).
2. Localize and mark the artery on the skin prior to making the incision.
3. Make a 5 cm oblique anterior bikini incision just distal to the ASIS, starting just distal to the ASIS and extending distally and medially.
4. Identify the tensor fascia lata/sartorius interval and open it by placing a hemostat or tenotomy scissors into the soft spot below the ASIS to open the fascia.
5. Identify the fat stripe associated with the lateral femoral cutaneous nerve and isolate/protect the nerve.
6. Deep to the interval is the rectus femoris tendon; dissection is carried out medially to palpate the pelvic brim.
7. Flex the hip to identify and expose the psoas tendon - use a Sofield retractor to elevate the psoas muscle.
8. Perform 3 essential tests to confirm the psoas tendon prior to dividing it:
    - Identify muscle fibers entering the tendon.
    - Confirm tightening with internal hip rotation.
    - Ensure the leg does not "jump" with brief electrocautery stimulation.
9. Retract the muscle fibers and divide the psoas tendon using electrocautery, ensuring to leave the muscle intact.
10. Close the subcutaneous tissue with absorbable 2.0 sutures and the skin with running 3.0 absorbable monofilament sutures.
11. Postoperatively, advance diet, provide pain control, initiate physical therapy (avoid hip flexion, prone positioning 6 hrs/day), and manage the wound (remove dressings by postoperative day 2) [12].

(3) Hamstring Lengthening

Hamstring lengthening may be done open or percutaneously.

Percutaneous approach:

Key steps for the percutaneous approach:

1. Position the hip at 90 degrees of flexion and the knee extended to place tension on the hamstrings.
2. Identify the semitendinosus tendon, which is the most superficial posteromedial structure.

3. Using a no.15 blade, make an incision directly lateral and anterior to the semitendinosus tendon, with the blade directed medially and parallel to the posterior thigh.
4. Fully insert the blade, then apply gentle posterior pressure while pushing the tendon against the blade to release the tendinous portion of the semitendinosus.
5. If the semimembranosus is also tight, use the no.15 blade to lengthen it through the same incision by directing the blade medially as it is advanced anteriorly, cutting the aponeurosis while leaving the underlying muscle intact.
6. It is critical to stay superficial in the posterior thigh and avoid going too deep toward the neurovascular structures.
7. If the biceps femoris is very tight, make a separate percutaneous incision just on the medial border of the aponeurotic band. Perform a single-level recession with the blade directed posterolaterally and then laterally as it is advanced.

Open technique:

Key steps for the open approach:

1. Position the patient supine.
2. Make a 3-5 cm midline incision in the distal third of the posterior thigh.
3. Dissect sharply to expose the semitendinosus tendon, which is the most superficial posteromedial structure.
4. Incise the deep fascia with tenotomy scissors to isolate the semitendinosus tendon.
5. Place a right-angle clamp around the semitendinosus tendon from lateral to medial to minimize neurovascular risk.
6. Transect the semitendinosus tendon at the musculotendinous junction using electrocautery.
7. Isolate the semimembranosus and incise its aponeurosis transversely at 1-2 levels, leaving the underlying muscle undisturbed.
8. Test the release by bringing the knee into full extension - if >20 degrees of residual flexion deformity, also lengthen the biceps femoris.
9. Close the wound in layers with absorbable sutures.
10. Postoperative management includes knee immobilizers, early physical therapy, pain control, and follow-up in 1-2 weeks.

The key principles are careful dissection, selective lengthening of tight tendons while preserving muscle, and avoidance of neurovascular injury.

(4) Gastrocnemius Recession

Surgical strategies to correct ankle equinus are based on clinical evaluation. The Silfverskiöld test is the gold standard for determining whether equinus deformity is caused by isolated gastrocnemius tightness (positive test) or tightness of the entire triceps surae (negative test). The surgeon must balance the degree of correction needed with the potential for muscle weakening and rehabilitation time when selecting the appropriate surgical level [19, 20].

Surgical techniques to address ankle equinus can be performed at 5 different anatomical levels, as illustrated in (Figure 1). The correction capacity is greater for more distal releases, with maximum correction when performed at the Achilles tendon. However, the greater the elongation, the weaker the muscle becomes. The possibility of developing harmful secondary changes then increases.

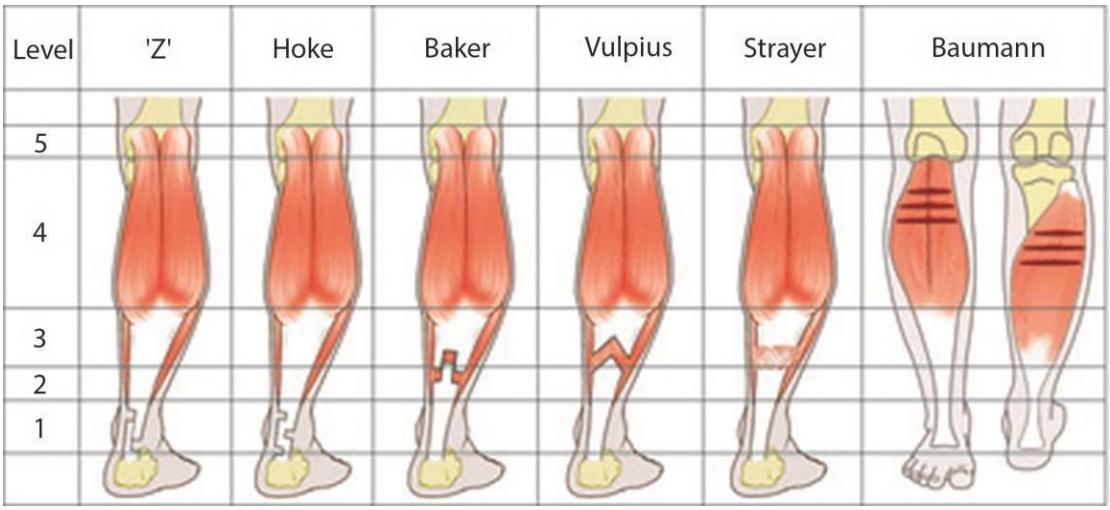

Figure 1 : Anatomical levels of the triceps surae and the most common surgical procedures at each level for equinus correction [21].

Vulpius Technique:

- Performed through a longitudinal midline incision at the musculotendinous junction.
- An inverted "V" or "U" shaped incision is made through the aponeuroses of the gastrocnemius and soleus, exposing the intact soleus muscle.
- Dorsiflexion is then applied to lengthen the muscle-tendon unit [21].

Baker Lengthening:

- Performed in the same region as the Vulpius technique.
- But the incision is made in an inverted "U" shape, rather than an inverted "V".
- Dorsiflexion is achieved by separating the horizontal arm of the "U" shaped incision [21].

Strayer Technique:

- Indicated for spastic equinus, especially with a positive Silfverskiöld test (isolated gastrocnemius tightness).
- Performed through a midline incision over the musculotendinous junction.
- The gastrocnemius aponeurosis is sectioned, with optional additional sectioning of the soleus aponeurosis or median raphe if needed [19].

Baumann's Technique:

- Provides the least amount of correction compared to the other techniques.
- Involves making multiple transverse incisions in the aponeurotic portions of the gastrocnemius and soleus to allow them to slide over each other [22].

Fasciotomy of Medial Gastrocnemius:

- Indicated for painful foot conditions like metatarsalgia and fasciitis.
- Involves a small transverse posterior incision to release the fascia of the medial gastrocnemius head [23].

Key postoperative management points:

1. Assess ankle dorsiflexion with the foot inverted.
2. Perform multi-layer subcuticular closure.
3. Immobilize the foot in 5-10 degrees of dorsiflexion and inversion.
4. Provide pain control, physical therapy, and appropriate follow-up.

5. The choice of surgical technique depends on the specific clinical presentation and the results of the Silfverskiöld test to determine the primary contributor to the equinus deformity [15].

(5) For Achilles tendon Lengthening

Percutaneous three-step cut technique:

1. Place the patient prone, apply a thigh tourniquet, and draw anatomic landmarks: medial and lateral border and insertion in the calcaneus.
2. **Perform the first tenotomy:**
    - Make the first medial cut at the insertion of the tendon onto the calcaneus, extending as one-half of the width of the Achilles tendon.
    - If the heel is in varus, place the first and third cuts on the medial side.
    - If the heel is in valgus, place the first and third cuts on the lateral side.
3. **Perform the second tenotomy:**
    - Make the second tenotomy proximally and medially just below the musculotendinous junction.
4. **Perform the third tenotomy:**
    - Make a cut midway between the first two cuts laterally through half the width of the tendon midway between the two medial cuts.
5. **Position the ankle:** Dorsiflex the ankle to the desired angle.
6. **Cover the incisions:** These incisions do not require closure. Place a sterile dressing on each incision.
7. **Place a long leg cast with the knee in full extension.** Weight bearing as tolerated on the leg.
8. **Postoperative management:** Pain medication, wound care, and schedule follow-up in 4 weeks [24].

Open Z-plasty technique:

1. **Incision and Exposure:**
    - Make a posteromedial skin incision (~ 6 cm) starting proximal to the calcaneal insertion.
    - Dissect through subcutaneous tissue to identify and incise the paratendon, exposing the Achilles tendon.
2. **Z-Lengthening Technique:**
    - Split the tendon longitudinally in the mid-portion and extend the split to the calcaneal insertion. Transversely transect the medial portion and continue the longitudinal split proximally.
    - Finally, transect the tendon transversely at the proximal extent, creating a "z" configuration.
3. **Tendon Repair:**
    - Dorsiflex the ankle to neutral and reapproximate the tendon under moderate tension using non-absorbable sutures.
4. **Closure and Post-Procedure Care:**
    - Approximate the paratendon end, as maintaining the integrity and attachments of the paratenon is important for blood supply. Then close subcutaneous tissue and skin. Apply a short leg cast with the ankle in neutral dorsiflexion.
5. **Considerations and Precautions:**
    - Verify the Silfverskiold test intraoperatively; avoid lengthening if positive. Address associated joint contractures and ensure proper patient positioning. Monitor for recurrence of contractures postoperatively [25, 26].

(B) Osteotomies

Osteotomies as a part of SEMLS are used to make improvements to joints. A surgeon can realign bones to help a child with movement and posture. The effect is often greater mobility and independence, and less pain from joints moving incorrectly.

There are different types and indications for osteotomies:

1. **Proximal femoral varus derotational osteotomy (VDRO):** indicated in hip subluxation or dislocation.

Procedure: Varus, derotation, and shortening proximal femoral osteotomy in the intertrochanteric region of the femur with the distal fragment medially displaced and secured with plate fixation, iliopsoas tendon released from the lesser trochanter.

2. **Proximal femoral rotational osteotomy:** indicated in anteversion or retroversion.

Procedure: Femur is rotated below the lesser trochanter and fixed with an internal fixation plate.

3. **Chiari pelvic osteotomy:** indicated in hip subluxation or dislocation with acetabular dysplasia.

Procedure: Periarticular pelvic osteotomy above acetabulum with the entire acetabulum shifted medially and fixed with hardware.

4. **San Diego/Degas Pelvic Osteotomy:** indicated in hip subluxation or dislocation with acetabular dysplasia.

Procedure: Peri-articular pelvic osteotomy above the acetabulum into tri-radiate cartilage with the roof of the acetabulum shifted laterally and distally using iliac or femoral interpositional bone graft and hardware fixation if needed.

5. **Distal femoral rotational osteotomy:** indicated in femoral anteversion or retroversion.

Procedure: Femur is rotated at the distal femoral metaphysis and fixed with internal hardware, either plates or wires.

6. **Distal tibial rotational osteotomy:** indicated in internal or external tibial torsion.

Procedure: Rotational tibial and fibular osteotomy with internal hardware fixation.

7. **Distal femoral extension osteotomy:** indicated in fixed knee flexion contractures and inability to extend at the knee during gait. The goal of the procedure is to improve knee extension range by altering the distal femur bony anatomy.

Procedure: Anterior femoral wedge is removed from the distal femoral metaphysis and fixed with a blade plate and side screws [27].

Complications of Operation

(a) General complications:

1. Infection.
2. Bleeding.
3. Wound healing problems.
4. Deep Vein Thrombosis (DVT).
5. Pulmonary Embolism (PE).

(b) Specific complications:

1. Abduction contractures if the obturator nerve is injured.
2. Overlengthening of the triceps surae leading to crouch gait.
3. Excessive hip flexor weakness with tendon release at the lesser trochanter.
4. Femoral neurovascular injury.
5. Recurrence.
6. Instability.
7. Worsened anterior pelvic tilt.
8. Genu recurvatum: much more common after combined medial and lateral hamstring lengthening than with isolated medial hamstring lengthening.
9. Neuropraxia.
10. Rupture of the Achilles tendon.
11. Sural neuritis
12. Postoperative swelling.
13. Calf weakness [9].

Postoperative Rehabilitation Program

(From day of surgery to 6 weeks postoperatively)

In the operated limb (which was in cast): Assisted active to active ROM exercises for unfixed joints (e.g. hips, toes) as tolerated was recommended along with strengthening of the muscles acting on unrestricted joints, from isometric progressed to isotonic exercises. Best position in bed for hips, knees, and ankles; elevation for edema control; trunk exercises; and assisted transfer education were also recommended. Weight bearing as tolerated only initiated.

(From 6 to 12 weeks postoperatively)

This period was very important for regaining ROM and muscle strength. ROM exercises were started in previously restricted joints. Starting of isometric strengthening exercises in muscles acting on previously restricted joints progressed to isotonic and resistance exercises. Use of heating modalities on stiff joints was common to decrease pain and improve ROM (e.g. infrared radiation) with caution to avoid burns to the child. Electric neuromuscular stimulation was added in cases with muscle recession or transfer. Stretching exercises were started to maintain muscle length and avoid contractures and deformities of the hip, knee, and ankle flexors and adductors according to each case condition and lengthening interventions. Partial weight bearing was started with the use of orthotic devices and walker and/or parallel bar for gait training. Instructions for use of orthotic devices according to each case condition were as follows: mostly knee ankle foot orthosis was described for night positioning, ankle foot orthosis, or ground reaction ankle foot orthosis for ambulation (in case of quadriceps muscle weakness or lag). Session frequency: five times per week for 1-2 hours. Home program of simple exercises and positioning was described for adolescent children as well as parents.

(From 3 to 6 months)

Continuation of the orthotic device was done. Progressive ROM, strengthening, and stretching exercises were recommended, along with assisted balance exercises (static to semidynamic balance), and increased ambulation distance.

(From 6 to 9 months)

Continuation of the previous items, along with continuation of day use of orthotic devices was recommended. Moreover, return to preoperative level of walking and community participation was suggested.

(From 9 to 12 months)

This period led to progression to better gait, independence, and dynamic activity. The frequency of sessions was reduced for most children and was replaced with recreational activities, including family walks, bicycle riding, and sports participation [28].

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