THE KNEE IN CEREBRAL PALSY: CURRENT MANAGEMENT FROM LESSONS LEARNT THROUGH THREE DIMENSIONAL GAIT ANALYSIS[1]

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INTRODUCTION
Orthopaedic priorities by topographic classification
Hemiplegia: Foot/Ankle: equinus, equinovarus, equinovalgus.
Diplegia: Knee: sagittal plane balance for walking.
Quadriplegia: Spine/Pelvis/Hip: sitting balance

THE EVALUATION
“Diagnostic Matrix” Davids et al [2]- information is gathered from the following five sources (Figure 1):
1. Clinical history: GMFCS, FMS, FAQ
2. Physical examination
3. Instrumented gait analysis
4. Special investigations including radiology
5. Examination under anesthesia

Figure 1: Diagnostic Matrix
**Physical Examination Of The Knee**

- Muscle spasticity (R1 vs. R2)
- Popliteal angle
- Muscle Contracture
- Duncan Ely/Prone rectus
- Knee Joint Contracture
- Fixed Flexion Deformity

**Gait Analysis**

Understanding the gait pattern and the interrelationship of the hip, knee, and ankle helps guide treatment.

4 Sagittal Knee Patterns: *Sutherland and Davids*[3]:

1. Jump Knee – increased knee flexion in early stance; normal knee extension in late stance
2. Crouch – increased knee flexion and ankle dorsiflexion in stance
3. Stiff Knee – decreased knee flexion in swing
4. Recurvatum Knee – excessive knee extension in stance

4 Sagittal Gait Patterns: *Rodda and Graham*[4] (Figure 2):

1. True equinus – hip normal; knee normal; ankle equinus
2. Jump Gait – hip normal; knee flexed; ankle equinus
3. Apparent Equinus – hip/knee flexed; ankle plantigrade
4. Crouch Gait – hip/knee flexed; ankle dorsiflexed

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**Sagittal Gait Patterns: Spastic Diplegia**

- **Group I**
  - True equinus
- **Group II**
  - Jump gait
- **Group III**
  - Apparent equinus
- **Group IV**
  - Crouch gait

- $\alpha > 90^\circ$
  - Gastroc
  - Hamstrings/RF (Psoas)
  - Hinged AFO

- $\alpha = 90^\circ$
  - (Gastroc) Hamstrings/RF
  - Psoas
  - Solid AFO

- $\alpha < 90^\circ$
  - Hamstrings/RF
  - Psoas
  - GRAFO

**Figure 2:** Four sagittal gait patterns in spastic diplegia *Rodda and Graham*[4].
KNEE INTERVENTIONS IN SPASTIC DIPLEGIA

Non-Operative Management

Strengthening:
- Important component of management particularly
  - Post multilevel orthopaedic surgery (and even in preparation)
  - Mild cases of diplegia
  - Adolescence
- Short term: strength improves with isometric training[5, 6]
- Detraining occurs as early as six weeks after cessation of the program[6]
- The relationship between improved strength and gait is uncertain. Gait kinematics show wide variability following an eight-week progressive resistance exercise program[7]

Spasticity Management For Knee Dysfunction[8, 9]:
- Oral medications – diazepam (Valium) for acute postoperative pain and spasm management. Not for chronic management.
- Botulinum Toxin A (BoNT-A) – targets specific muscle groups;
  - Hamstring injections Corry et al[10]
    - Improves knee extension at initial contact – six degrees
    - Maximal knee extension in stance – eight degrees
    - Improvements no longer present at 12 weeks
  - defers multilevel orthopaedic surgery until an appropriate age Molenaers et al[11]
  - effective in the short term, but is never definitive
- Selective dorsal rhizotomy – useful for severe hypertonia in carefully selected cases
- Intrathecal baclofen pump – for generalized hypertonia

Operative Management

Flexed knee gait cannot be managed by a single approach. Applying the diagnostic matrix (clinical history, physical examination, gait analysis, radiology, and examination under anesthesia) helps determine the “surgical dose.”

Distal Hamstring Lengthening

Establishing whether the hamstrings are or are not short and contracted is paramount prior to undertaking any hamstring lengthening procedure as the prevalence of short, contracted hamstrings in spastic diplegia has been shown by studies using muscle length modeling, to be less frequent than previously thought[12].

A variety of techniques for hamstring lengthening are utilized:
- Semimembranosus lengthening by a number of circular stripes in the fascia over the distal muscle, followed by gentle extension of the knee, allows lengthening in continuity while preserving the underlying muscle and muscle function.
- Gracilis and semitendinosus lengthening by simple tenotomy, Z-lengthening or intramuscular lengthening have been described.
Lateral hamstring lengthening in addition to medial hamstring lengthening is more controversial due to:

- Risk of knee recurvatum [13].
- Risk if increased anterior pelvic tilt [14].

Presenters’ Preferred Method

- Less commonly performing isolated distal hamstring lengthening because the knee dysfunction is often too mild or too severe to benefit.
- We lengthen the medial hamstrings only, to minimize the risk of recurvatum and minimize the risk of increased anterior pelvic tilt.
- To maintain the integrity of the muscle-tendon-unit, the semimembranosus is fractionally lengthened with one or two circumferential stripes in the fascia, and the semitendinosus and gracilis are lengthened by intramuscular technique, similar to that described for the lengthening of the tibialis posterior [15] (figure 3B).
- We always use intramuscular tenotomy to preserve continuity and function.
- Now we almost never lengthen biceps femoris.

Distal hamstring lengthening is combined with other procedures, such as a semitendinosus transfer, for mild to moderate degrees of fixed flexion deformity at the knee, greater than 5 degrees.
Figure 3: Schematic representation of knee interventions in spastic diplegia. A) For spastic muscle contracture, spasticity management may include botulinum toxin A injections (BoNT-A), selective dorsal rhizotomy (SDR) and occasionally intrathecal baclofen (ITB). B) Fixed muscle contractures are addressed by medial distal hamstring lengthening. C,D) Useful tendon transfers include a rectus femoris transfer or semitendinosus transfer. E) Fixed knee flexion contracture may be addressed by supracondylar extension osteotomy and patellar tendon shortening. F) When growth is remaining, guided growth can be employed, applying “8” plates across the anterior distal femoral physis.
Rectus Femoris Transfer

Distal hamstring lengthening in isolation improves knee extension during stance phase but results in decreased flexion during swing phase and increased stiffness[16]. This may result in clearance problems, toe scuffing and increased energy expenditure[17]. A solution to this problem is to combine medial hamstring lengthening with transfer of the rectus femoris.

The indications include:
- GMFCS level - the best results of rectus femoris transfer are in GMFCS I and II patients[18].
- Rectus femoris spasticity - confirmed by the Duncan-Ely or prone rectus test [17, 19].
- Kinematic variables including decreased peak knee flexion in swing phase[19], a decreased knee range of motion during swing phase[17, 20], a decreased overall knee range of motion during the gait cycle, and a delay in the timing of peak knee flexion[19].
- Dynamic EMG showing prolonged rectus firing during swing phase [17, 20].

With respect to surgical technique:
- Distal rectus femoris transfer yields better results than either proximal or distal rectus femoris lengthening [20-22].
- No evidence that one site of transfer is superior to another [23, 24].
- Medially, the most commonly used recipient tendons for the rectus femoris transfer are the semitendinosus, the gracilis or the sartorius.
- Laterally, the iliotibial band has been used as a recipient tendon.
- Distal rectus femoris intramuscular lengthening has been recently described and the benefits found for patients requiring soft tissue surgery only, were maintained peak knee flexion and improved timing of peak flexion in swing phase and decreased knee flexion in stance[25].

**Presenters’ preferred method**

We transfer the rectus femoris medially to the semitendinosus (figure 3C). A sound tendon-to-tendon transfer and secure repair allows early active and passive mobilization postoperatively. The proximal segment of semitendinosus is cross-sutured to semimembranosus to preserve proximal hip extensor function.

Sometimes indications are not clear and the rectus femoris transfer is delayed when:
- Clinical and kinematic indications for rectus femoris transfer are borderline.
- Anticipated immediate postoperative rehabilitation may be too complex for the child or the family to be sure of achieving a good result.
- There is concern of precipitating crouch gait in a child who already has an excessive knee flexion throughout stance phase.

A second opportunity arises for rectus femoris transfer when internal fixation implants are removed, such as blade plates following a femoral osteotomy. If knee extension has been successfully restored, our preferred technique is then to transfer the rectus femoris laterally to the fascia lata.
Medial Hamstring Lengthening Combined with Semitendinosus Transfer to the Adductor Tubercle

In the past, transfer of some or all of the hamstrings to the distal femur was described by Eggers and colleagues[26]. However, the procedure was abandoned when it was found that intractable recurvatum developed very quickly[27]. In order to improve knee extension without causing recurvatum, some centers transferred a single hamstring instead.

The indications for semitendinosus transfer in our center include:
- Severe knee flexion throughout the stance phase.
- Fixed knee flexion deformity, five to 20 degrees, when examined under anesthesia.
- GMFCS level III or IV, and sometimes a young patient categorized as a GMFCS II with early fixed flexion contractures.

Semitendinosus transfer is contraindicated in patients without a fixed knee flexion contracture given the high risk of recurvatum.

Outcomes [28]:
- Fixed knee flexion deformity improved 15 degrees, from 18 degrees preoperatively to three degrees postoperatively.
- Knee flexion at initial contact improved by 17 degrees, from 39 degrees preoperatively to 22 degrees postoperatively.
- Minimum knee flexion during stance phase improved by 18 degrees, from 26 degrees preoperatively to 8 degrees postoperatively.
- Pelvic tilt did not deteriorate.
- Significant improvements were noted in the Functional Mobility Scores (FMS) at five and 50 meters.

Presenters’ Preferred Method

The semitendinosus is harvested distally from its attachment to the pes anserinus and transfer to the adductor magnus tendon. The procedure is performed in combination with conventional lengthening of the semimembranosus by fascial striping and an intramuscular lengthening of the gracilis (figure 3D).

Semitendinosus transfer may exaggerate knee stiffness problems in swing. Our approach to this situation is to accept the short term knee stiffness. Once we think the correction of the sagittal plane is stable with no residual knee flexion deformity and good extension during stance phase, an isolated transfer of the rectus femoris to the fascia lata maybe considered.

The benefits of combined distal medial hamstring lengthening and semitendinosus transfer can be augmented by guided growth, as described in a later section.

Supracondylar Extension Osteotomy and Patellar Tendon Shortening

Distal hamstring lengthening in the presence of knee flexion deformity of more than five to 10 degrees is ineffective and risks complications such as common peroneal nerve stretch injuries and increased anterior pelvic tilt. Correction of knee flexion deformity by a supracondylar extension
osteotomy(SEO) in combination with patellar tendon shortening (PTS) is more effective. Indications for SEO-PTS include:

- severe crouch gait
- knee flexion deformity of 10 to 30 degrees
- an extensor lag greater than 10 to 20 degrees
- patella alta on radiographs

The combination of a SEO and PTS addresses the static knee flexion contracture and the dynamic extensor lag. SEO is performed by excision of a trapezoid wedge from the distal femur and stable internal fixation with a blade plate. The patellar tendon may be advanced or shortened.

Outcomes[29]:
- Knee extensor lag improved 14 degrees, from 16 degrees preoperatively to 2 degrees postoperatively.
- Knee flexion at initial contact improved 16 degrees, from 42 degrees preoperatively to 26 degrees postoperatively.
- Minimum knee flexion in stance improved 29 degrees, from 38 degrees preoperatively to 9 degrees postoperatively.

Presenter’s Preferred Method

SEO and PTS are performed in skeletally mature patients, or near skeletal maturity with less than 2 years growth remaining. When the distal femoral growth plate is open, the osteotomy must be performed more proximally because the insertion of the blade plate must be between one and two cm proximal to the growth plate to avoid injury to the physis. A proximal osteotomy causes a secondary translation deformity.

Our technique for patellar tendon shortening was adopted from the Association for Assistance of the Disabled Child (AACD) in São Paulo, Brazil, as shown in figure 3E[30].

1. The patellar tendon is divided in its mid substance.
2. The distal segment is prepared with a non-absorbable suture and passed proximally through two drill holes along the longitudinal axis of the patella.
3. The proximal segment is repaired over the distal segment to reinforce the repair.
4. Postoperatively the patient’s lower extremity is immobilized in a long leg cast for six weeks. This is followed by six more weeks in a solid AFO with a 3-point splint or rigid knee splint. Immobilization of the knee in extension for periods of up to three months is inconvenient but has no bearing on long term function. In spastic diplegia, the knee does not become stiff in extension, but it may do so in flexion.

The Ferraretto and Selber technique is both safe and effective. It can be safely used in skeletally immature children in whom advancement of the tibial tuberosity may risk disturbing growth in the anterior tibial apophysis and cause a recurvatum deformity. The technique is effective in correcting patella alta extensor lag and improving stance phase knee extension. Finally there is no retained hardware in the knee extensor mechanism to be removed or cause secondary morbidity.
Guided Growth

Guided growth is helpful for children with spastic diplegia who present with severe crouch gait and progressive knee flexion contractures well before skeletal maturity. Guided growth is less invasive than SEO-PTS.

Indicated for [31]:
- Fixed knee flexion deformity of more than 10 degrees
- 12 months or more predicted growth remaining
  Staples[32] or “8” plates[31] placed anteriorly, spanning the distal femoral growth plate creates differential growth of the distal femoral physis, with the anterior portion growing more slowly than the posterior portion. Over time, this may correct the flexion deformity.
  Outcome of “8” plates[31]: Knee flexion deformity decreased by 0.9 degrees/month, correcting knee flexion by an average of 12.7 degrees.

Presenter’s Preferred Method
- In skeletally immature patients with knee flexion contractures greater than 10 to 20 degrees, we consider combining guided growth with medial hamstring lengthening and semitendinosus transfers.
- In children with greater than two years of growth remaining, we typically use “8” plates.
- Once the correction is achieved, we often remove the proximal screw of the “8” plate if the patient has growth remaining after complete correction, so that it may be reapplied if necessary in the future.
- The “8” plates are applied outside the periosteum and the effects are reversible once removed.
- One disadvantage of “8” plates is that they are prominent and at times have been noted to cause a local bursitis, although the exact incidence is not well documented. It seems that patients with significant dystonia can be particularly affected.
- Staples are less prominent, but reversibility is not guaranteed. Therefore, we use staples in children who are within two years of reaching skeletal maturity and in whom bone age is known accurately. Otherwise, we believe there would be a significant and unacceptable risk of recurvatum deformity at the knee. Recurvatum gait in the adolescent can be particularly difficult to correct.

MEASURING OUTCOMES

Knee function following an intervention can be assessed by:
- The Diagnostic Matrix – the patient’s symptoms, physical exam measures, gait analysis, radiology, etc.
- Functional outcome measurements include the FAQ[33] and the FMS[34].
- The Movement Analysis Profile (MAP) and the Gait Profile Score (GPS)[35]

SUMMARY: WHAT’S THE DOSE?

Deciding the surgical “dose” is a useful concept in the management of knee dysfunction in cerebral palsy. In order of increasing “dose” we think the interventions for improving knee extension include:
• **Injections of botulinum neurotoxin A** as a temporizing measure for hamstring spasticity.
• **Medial hamstring lengthening** for mild knee dysfunction, usually younger patients with mild jump gait and minimal flexion deformity, less than 5 degrees
• **Medial hamstring lengthening combined with semitendinosus transfer to the adductor tubercle** for more severe flexed knee gait and mild to moderate knee flexion deformities, 5-15 degrees.
• **Transfer of the semitendinosus combined with growth plate surgery** for severe flexed knee gait, combined with knee flexion deformities of 10-25 degrees in the patients with at least two years of growth remaining.
• **Supracondylar extension osteotomy combined with patellar tendon shortening** for severe flexed knee gait, combined with knee flexion deformities of 10-30 degrees, in patients with severe quadriceps lag who are either close to or already at skeletal maturity.

REFERENCES:


