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An Update on the Treatment of Gait Problems in Cerebral Palsy

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Summary: This article summarizes our experience with cerebral palsy over the past 20 years. The primary and secondary deformities that occur with cerebral palsy are described. Following this, there is a brief overview of the nature and role of gait analysis in the treatment of gait problems in cerebral palsy. The concept of lever-arm dysfunction is introduced. Our current treatment algorithm is then presented along with a brief discussion of our current treatment program, which is illustrated by a case example. Finally, a brief study of a group of patients with spastic diplegia or quadriplegia is presented to illustrate our current method of evaluating treatment outcomes and the need for team management in the treatment of this complex condition. **Key Words:** Cerebral palsy—Gait—Outcome assessment—Treatment protocol—Rhizotomy.

There has been enormous progress in the treatment of gait problems in children with cerebral palsy in the past 20 years. As such, a myriad of treatments is now available for these children that ranges from the standard orthopaedic procedures to spasticity reduction via an intrathecal Baclofen pump or selective dorsal rhizotomy. In the past, when treating these children, we started with a child with spasticity and orthopaedic deformities who walked poorly, and ended with the same child who walked differently. This was because, without modern technology, it was very difficult to assess the benefits or detriments of our interventions. Now, with the advent of gait analysis laboratories, functional assessment scales (7), patient satisfaction questionnaires and energy cost analysis, we can assess the outcomes of treatment interventions much more precisely (7). Furthermore, third-party payers are now demanding that we carry out these assessments. Consequently, it is becoming increasingly clear that, in the very near future, we are going to be held accountable for our treatment outcomes.

If we are going to offer these children consistent and optimal treatment, it should be apparent that we are going to have to operate under a new set of guidelines. The team of individuals who are going to treat a child with cerebral palsy must have:

1. knowledge of normal anatomy and physiology, particularly with reference to ambulation,
2. a good understanding of the functional pathology present in cerebral palsy,
3. realistic goals/objectives for treatment that are shared commonly by the patient, family, and others concerned with the child's welfare,
4. knowledge and ability to carry out any of the treatments that are required, and
5. a facility with the resources to carry out the necessary evaluations/treatments.

Because Gillette Children's Specialty Healthcare has become a center for the treatment of cerebral palsy, we have had an opportunity to see the long-term outcomes of many children who have undergone previous surgery before coming to our facility. Unfortunately, many of these individuals have been harmed because the listed guidelines were not followed. While many of the surgical procedures used in the treatment of cerebral palsy are technically easy to do, the decision-making that is necessary before the treatment of cerebral palsy is undertaken is very complex. Hence, we have seen children who have had inappropriate surgical procedures (i.e., surgeries that did not address the underlying

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pathology). Unfortunately, the adverse effects of such treatment are usually permanent and irrevocable.

Because of its limited scope, this article cannot offer the reader comprehensive knowledge in all these areas. Rather, the goal of this article is to provide an overview of modern treatment and an update on the status of progress in this field. It is also the authors' hope that it will become apparent to the reader that cerebral palsy is a condition that should not be treated casually. Expertise is required to effectively treat gait problems in children with cerebral palsy. Those who are unwilling or unable to meet the listed guidelines should refer these children to a treatment center.

Attempts to improve ambulation in cerebral palsy must begin with knowledge of normal gait. Normal gait is a complex topic in itself, but thanks to the work of pioneers like Vern Inman, Jacquelyn Perry and David Sutherland (6,8,10,11), it is now fairly well understood. Consequently, we will presume in this article that the reader understands the principles of normal gait. What is not as well understood is the effect of the pathophysiology of cerebral palsy on ambulation. Therefore, in discussing the treatment of cerebral palsy, we must start there because, once this knowledge is obtained, appropriate treatment programs follow logically.

TYPES OF GAIT DEVIATIONS IN CEREBRAL PALSY

In a child with cerebral palsy, it is the central control system that is damaged. The neurologic lesion may produce different tone abnormalities (spastic, athetoid, or mixed). In a patient who has pure spasticity, only the pyramidal system is damaged; in athetoid cerebral palsy, only the extrapyramidal system is involved; and in a mixed pattern, both systems are injured.

Despite the fact that the effects of cerebral palsy are readily apparent at the periphery (i.e., the muscles and bones of the extremities), it is only the central control system that is damaged. The changes in length, and/or structure that occur in the muscles and bones of the extremities are all secondary to the central nervous system lesion. In an individual with cerebral palsy, the primary injury (symptomatology owing directly to damage to the central control system) will produce some or all of the following primary abnormalities:

1. loss of selective muscle control,
2. dependence on primitive reflex patterns for ambulation,
3. abnormal muscle tone,
4. relative imbalance between muscle agonists and antagonists across joints, and
5. deficient equilibrium reactions.

The secondary abnormalities are best characterized as growth disorders. They develop over time in a growing child. Growth of bone occurs via epiphyseal plates, but it is the joint reaction forces acting on those bones that determine their ultimate shape. If those forces are correct, the final shape of the bone will be correct. If the forces are distorted, the final shape of the bone will be distorted. In simple terms, bone growth follows the Star Wars Principle: "Let the force be with you!". Consequently, in conditions such as spastic diplegia, both remodeling of fetal bone alignment and future modeling of bone as it grows are abnormal. As such, deformities such as hip subluxation, torsion of long bones, and foot deformities are common.

Muscle growth, conversely, is driven by stretch. It has been shown that, for normal muscle growth to occur, 2 hours to 4 hours of stretch per day are necessary (12). Normally, that stretch occurs when a child, whose bones have grown during sleep, gets up and starts to run and play. However, "normal play" demands good overall body balance, excellent selective motor control and muscles with normal elasticity, none of which are present in a child with spastic diplegia.

In cerebral palsy gait, abnormalities never occur in isolation. Rather, they are multiple and consist of primary anomalies (owing to the damage to the central nervous system), secondary anomalies (from abnormal bone/muscle growth), and tertiary abnormalities. Tertiary abnormalities are those compensations that the individual uses to circumvent the primary and secondary abnormalities of gait. Thus, the tertiary abnormalities can be thought of as "coping responses". For example, co-spasticity of the rectus femoris and hamstrings commonly produces a stiff knee in the swing phase of gait. This, in turn, leads to problems with foot clearance. Circumduction of the swinging limb, by abducting the hip, is a frequent compensation. The primary deviation of gait in this example is the rectus femoris and hamstring co-spasticity. The "coping" response is the circumduction. Much of the difficulty encountered in studying pathologic gait involves the separation of the true pathology from these coping responses. However, good treatment demands their separation because, to optimize the efficiency of gait, we must correct the former and not interfere with the latter. The "coping responses" themselves will disappear spontaneously when they are no longer required.

GAIT ANALYSIS

In our opinion, dynamic gait analysis is now mandatory for optimal treatment of problems relating to ambulation in cerebral palsy. Before surgery, gait analysis allows accurate dynamic assessment of the patient's particular gait problems. Postsurgery gait analysis allows a much more accurate and objec-

tive assessment of outcome than was previously possible. Several good, commercial, gait analysis systems are now available. The more comprehensive of these provide the user with three-dimensional kinematics and kinetics as well as dynamic electromyography (3).

Kinematics are those parameters used to describe the spatial movement of the body, without consideration of the forces that cause the movement (e.g., body position, joint position, and joint motion). Kinematics essentially tell us "what" is occurring at each of the major lower extremity joints, but not "why" it is happening. Kinematics are very useful in comparing preoperative and postoperative gait analysis to determine treatment outcome. For example, they can help answer the question "Was treatment to correct or improve crouch gait successful?" (Fig. 1).

Kinetics are those parameters used to describe the mechanisms that cause movement (e.g., ground reaction forces, joint moments, joint powers). By using kinetics, we can often determine why a particular gait deviation is occurring (2). Therefore, information derived from the study of kinetics is especially useful to improve one's knowledge of the pathogenesis of gait problems.

In addition to gait analysis, many centers also measure oxygen consumption/cost during ambulation as a means of assessing the energy cost of the patient's gait. This is useful as an indicator of the degree of inefficiency of the gait. Consequently, we use oxygen consumption/cost as a barometer of the overall severity of dysfunction.

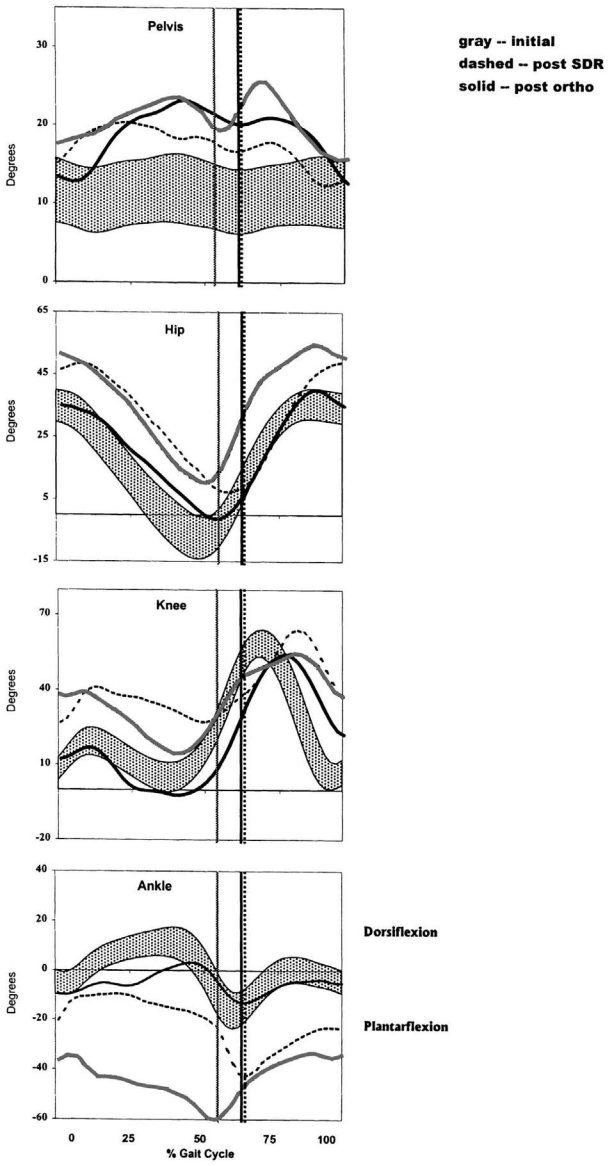

FIG. 1. Sagittal plane preoperative and postoperative kinematics of a child. From top to bottom, the graphs represent the kinematics of the pelvis, hip, knee, and ankle, respectively. The shaded band is the normal range, the gray line is the preoperative status, the dashed line is the child's kinematics following selective dorsal rhizotomy, and the solid line is the child's final result following lower extremity orthopaedic surgery to correct residual muscle contractures and lever-arm dysfunction. Pertinent findings include improved hip extension, elimination of crouch, improved knee range of motion during gait, improved knee extension in preparation for initial contact, and correction of equinus during stance and drop foot in swing. SDR, selective dorsal rhizotomy.

LEVER-ARM DYSFUNCTION

A lever-arm or moment-arm is best defined as a distance from a point to a force that is perpendicular to the line of action of that force. The force (measured in Newtons) multiplied by the length of the lever-arm (in meters) is equal to the moment that acts around the center of rotation. Consequently, the units of a moment are Newton-meters. In general, the lever acts along the length of the bone and the joint at the end of that bone serves as the center of rotation or fulcrum. The magnitude and direction of the moment depends on the point of action of the applied force (Fig. 2).

Moments are perhaps understood most easily if one thinks of a seesaw in which the mass of the larger individual times his/her distance from the fulcrum is equal to that of the smaller individual times her/his distance from the fulcrum (Fig. 3).

It is the same in walking. External moments produced by the ground reaction and inertial forces plus the segment weights are resisted by internal moments produced by the action of muscles, tendons, and/or ligaments (Fig. 4).

"Lever-arm dysfunction" is a term we originally coined to describe the particular orthopaedic deformities that arise in an ambulatory child with cerebral palsy (1). However, the condition is common to any traumatic or neuromuscular problem that produces alteration of the bony skeleton. Lever-arm dysfunction, then, describes a general class of bone modeling, remodeling, and/or traumatic de-

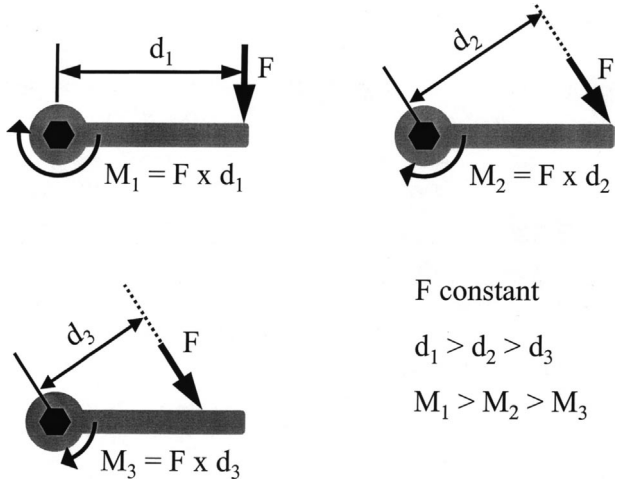

FIG. 2. The magnitude of a moment is the product of force and lever-arm. The lever-arm is the perpendicular distance between the force and the axis of rotation. A change in either the position or the orientation of the applied force can cause a change in the magnitude of the moment. To produce the greatest moment, the force should be perpendicular to the lever. M, moment; F, force; d, distance.

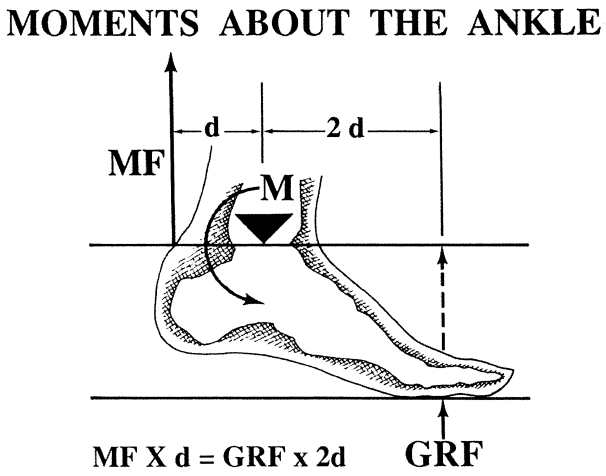

FIG. 4. The relationship between the external moment produced by the ground reaction force (GRF) and the internal moment produced by the force of the muscles (MF). In each case, they act on a skeletal lever and their fulcrum is the joint center. Since the lever-arm of the GRF is twice as long as that of the muscles, its magnitude is only one-half as much: MF/2 = GRF or MF = 2(GRF). d, distance.

formities that includes hip subluxation, torsional deformities of long bones, and/or foot deformities. Since the muscles and/or ground reaction forces must act on skeletal levers to produce locomotion, abnormalities of these lever-arm systems greatly interfere with the child's ability to walk (1,4).

In a condition such as cerebral palsy, the muscle and/or ground reaction forces are neither appropriate nor adequate because of muscle contractures, poor selective motor control, and/or abnormality of the bony lever-arms. With respect to the lever-arms themselves, five distinct types of lever-arm deformity exist: 1) a short lever-arm; 2) a flexible lever-arm; 3) a malrotated lever-arm; 4) an abnormal pivot or action point; and/or 5) a positional lever-arm dysfunction (Table 1). A comprehensive discussion of lever-arm dysfunction is beyond the scope of this article, but a common example of lever-arm dysfunction typically seen in spastic diplegia will serve as an illustration.

In normal gait during the second half of the stance phase, stability of the knee is maintained without quadriceps action through a mechanism termed "the plantar flexion/knee extension couple".

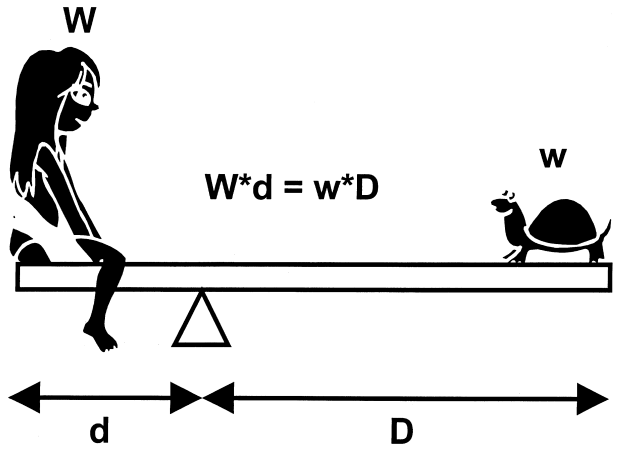

FIG. 3. A seesaw can be balanced with two individuals of different weight as long as the weight (W) of the heavier individual multiplied by his distance from the fulcrum (d) is equal to the weight of the lighter individual (w) multiplied by his distance from the fulcrum (D). Rotation of the seesaw occurs when one occupant pushes against the ground. When this happens, the effective weight (load) of that occupant is decreased. Since the weight of the other occupant (effort) is unchanged, the moments no longer balance. The system then transforms from a static system to a dynamic system. There is angular acceleration that, integrated over time, produces angular velocity and hence motions of the seesaw.

TABLE 1. *Examples of lever-arm dysfunction*

Type	Deformity
Short lever-arm	Coxa valga
Flexible lever-arm	Pes valgus
Malrotated lever-arm	External tibial torsion
Abnormal pivot or action point	Hip subluxation/dislocation
Positional lever-arm dysfunction	Erect versus crouch gait

The types of lever-arm abnormalities that can produce gait problems are listed with an example of each. The first four have the effect of reducing the magnitude and/or efficiency of the moment arm in its normal plane of action. Positional lever-arm dysfunction refers to the fact that the relative magnitude of the hamstring lever-arms at the hip and knee varies according to the position of the lower extremities. As a result of the positional changes in lever-arm length, the hamstrings are better hip extensors than knee flexors in erect posture. However, in crouch gait, the opposite is true (i.e., the hamstrings are better knee flexors than hip extensors).

That is, the action of the soleus at the ankle restrains forward motion of the tibia over the foot and in so doing maintains the ground reaction force in front of the knee. The result is that the ground reaction force acting on the lever-arm of the forefoot produces an extension moment at the knee, which in turn maintains the joint in extension without the aid of the quadriceps (Fig. 5). However, the typical child with spastic diplegia frequently has femoral anteversion in conjunction with pes valgus and/or external tibial torsion. As such, the plane of the foot is often as much as 40° external to the plane of the knee. In addition, a valgus foot is an ineffective lever because it is supple rather than rigid. As a result, even if the magnitude of the ground reaction force was normal, the magnitude of the extension moment would be greatly reduced because the lever-arm is supple and mal-directed (Fig. 6). Fortunately, lever-arm dysfunction is usually correctable with appropriate orthopaedic surgery and/or bracing.

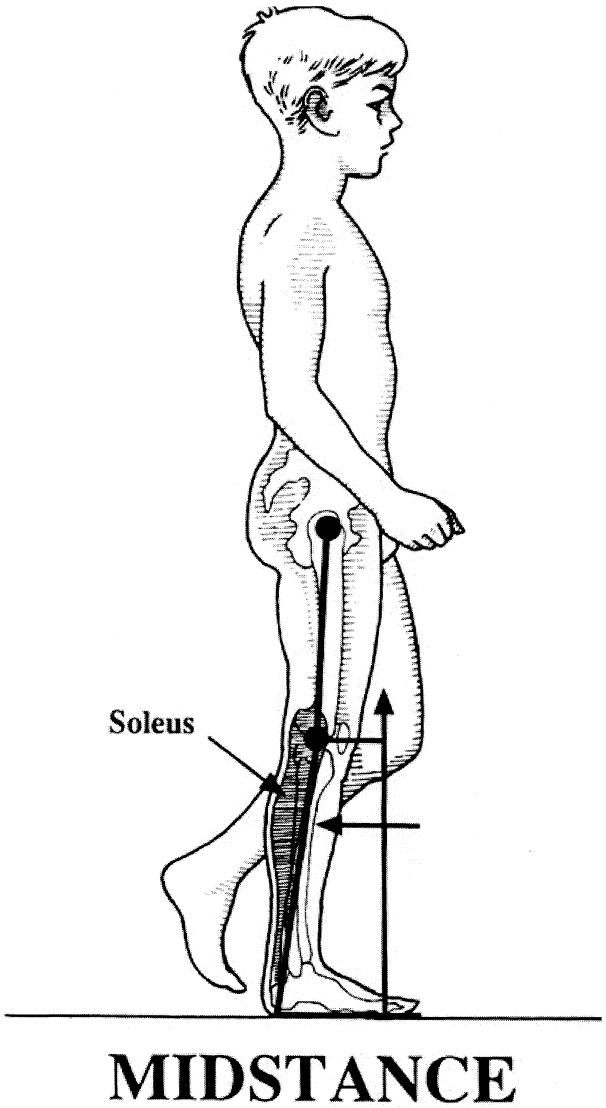

FIG. 5. Using the soleus to slow the forward momentum of the shank, the ground reaction force (GRF) is brought in front of the knee. The GRF acting on the lever-arm of the foot thereby generates an extension moment on the knee that provides the required joint stability without the necessity of quadriceps action. This moment is generally referred to as a plantarflexion/knee-extension couple.

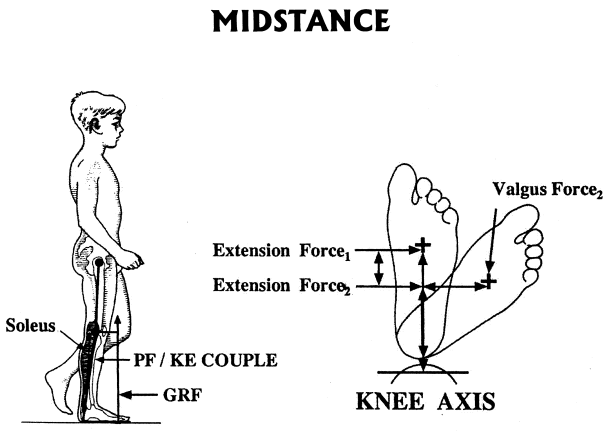

FIG. 6. An illustration of the effect of external foot rotation on the ground reaction force (GRF) moment. In normal gait at midstance, the GRF generates a pure extension moment at the knee, as shown on the left. External tibial torsion causes the GRF to move posterior and lateral to its normal position, as shown on the right. This has the effect of shortening the extension moment lever-arm. This means that the knee extension moment is reduced. In addition, valgus and external rotation moments are introduced that will generate valgus and external rotation forces at the foot, shank, and knee. In a growing child, these abnormal forces acting over time will produce pes planovalgus, further external tibial torsion, and genu valgum. PF, plantar flexion; KE, knee extension.

DECISION-MAKING IN AMBULATORY CEREBRAL PALSY

In summary, if we are going to treat cerebral palsy well we must understand the pathologic mechanisms that are the cause of the gait abnormalities. As discussed earlier, the primary problems of deficient selective motor control, abnormalities of balance and abnormal central nervous system tone drive the secondary abnormalities of inadequate muscle growth and bony deformity. The secondary abnormalities are amenable to treatment whereas, with the exception of spasticity, the primary abnormalities of cerebral palsy are difficult to alter. Consequently, we must learn to analyze the pathology, and to determine which portions of it can be corrected and which cannot.

Inadequate muscle growth can be treated by a variety of means including any of or all the following: 1) passive stretch; 2) night splinting; 3) physi-

cal therapy; 4) botulinum toxin; 5) phenol or alcohol injections; 6) orthopaedic lengthening; and/or 7) spasticity reduction.

Bone deformity (lever-arm dysfunction) is best corrected by orthopaedic surgery, but small deformities may be amenable to bracing.

Abnormal muscle tone is a primary problem and, as such, is more difficult to remedy. Minor degrees of tone abnormality can and should be accepted. Pure spasticity, if it is severe enough to treat, is probably best addressed by selective dorsal rhizotomy provided the child meets the other criteria for the procedure (i.e., pure spasticity, good selective motor control, adequate underlying muscle strength, age 4 years to 7 years, and diagnosis of diplegic cerebral palsy owing to prematurity). Children with spasticity or mixed tone, who do not meet the selection criteria for selective dorsal rhizotomy, are currently being treated at our center with the intrathecal Baclofen pump. In general, extrapyramidal tone is not amenable to treatment, although there are a few oral pharmacologic agents that can be tried.

Deficient selective motor control and abnormal balance mechanisms are permanent disabilities. Appropriate physical therapy is somewhat useful and should be used to maximize function, but currently there is no way to remedy these problems. As such, they are the limiting factors of treatment.

The knowledge of the pathologic gait of cerebral palsy already outlined must be applied to treatment. To achieve this, the following list of management principles of ambulatory disability in cerebral palsy can be useful in determining a specific treatment program.

1. Reduce spasticity.
2. Correct contractures.
3. Simplify the control system.
4. Preserve power generators.
5. Correct lever-arm dysfunction.

The first two principles broadly guide treatment decision-making at all ages (although one would use different treatment methods to accomplish each of these goals at different ages). The last three principles are applied when planning orthopaedic surgery. The flow chart depicted in Figure 7 illustrates the way that these principles are applied in making treatment choices to improve ambulation for children with cerebral palsy at our institution.

Spasticity management and correction of contractures can be addressed in many different ways (physical therapy, orthotics, botulinum toxin injections, oral spastolytics, selective dorsal rhizotomy, intrathecal Baclofen, and/or tendon lengthening). In practice, choosing among these options depends largely on the child's age. Global spasticity management is frequently the method of choice for children between ages 4 years and 7 years, whereas botulinum toxin injection and/or stretching casts are the better choices for younger children and/or adolescents in the midst of their growth spurt. The reader should be aware that there is very little definitive scientific evidence comparing the efficacy of each of these methods at different ages. The overall management scheme for decision-making as represented on the flow chart is based largely on clinical experience and knowledge of the pathomechanics of cerebral palsy. If careful quantitative assessment and evaluation of outcomes are used as a routine part of the treatment program, optimal methods of achieving specific treatment objectives will soon become apparent.

Conversely, significant lever-arm dysfunction should be managed regardless of age. Consider, for example, the unstable talipes equinovalgus foot that is so common in children with spastic diplegia. If we remember that moment-generating capability is dependent on both the ability to generate muscle force and the presence of an intact lever-arm, it will help us focus on the importance of correcting lever-arm dysfunctions such as pes valgus. For the very young child with milder deformity treatment with physical therapy and/or orthoses are most important. For older children, these are not adequate and surgical intervention is necessary. Choosing the correct surgical procedure(s) represents yet another level of complex decision-making. For example, with respect to the foot, options include os calcis lengthening, os calcis lengthening plus tightening of the medial/plantar talonavicular joint capsule with or without posterior tibial tendon advancement, and os calcis lengthening plus subtalar arthrodesis.

Plantar flexor moment insufficiency can be a debilitating cause of crouch gait at any age. For young children, botulinum toxin injection to the gastrocnemius in conjunction with a well-fitting, solid ankle–foot orthosis (AFO) to maintain foot alignment and stability may be appropriate.

For older children with crouch gait, careful assessment should be made for bony deformities such as external tibial torsion, distal tibial valgus, pes valgus, femoral anteversion, knee flexion contracture, and/or patella alta (usually associated with knee extensor lag). In addition, crouch gait can be because of soleus weakness. Consequently, physical therapy to strengthen the soleus and/or a rear entry floor reaction AFO should be considered. A fitness exercise program such as swimming or bicycling should be incorporated if possible. The benefits of improved weight management, cardiovascular health and overall muscle strength also are essential for improving function.

Methods of treatment in the age of spasticity management are different from when tendon lengthenings alone were performed. Decreased spasticity allows the child to have greater range of motion, less spastic response to stretch, and better potential to develop and use voluntary muscle activity during

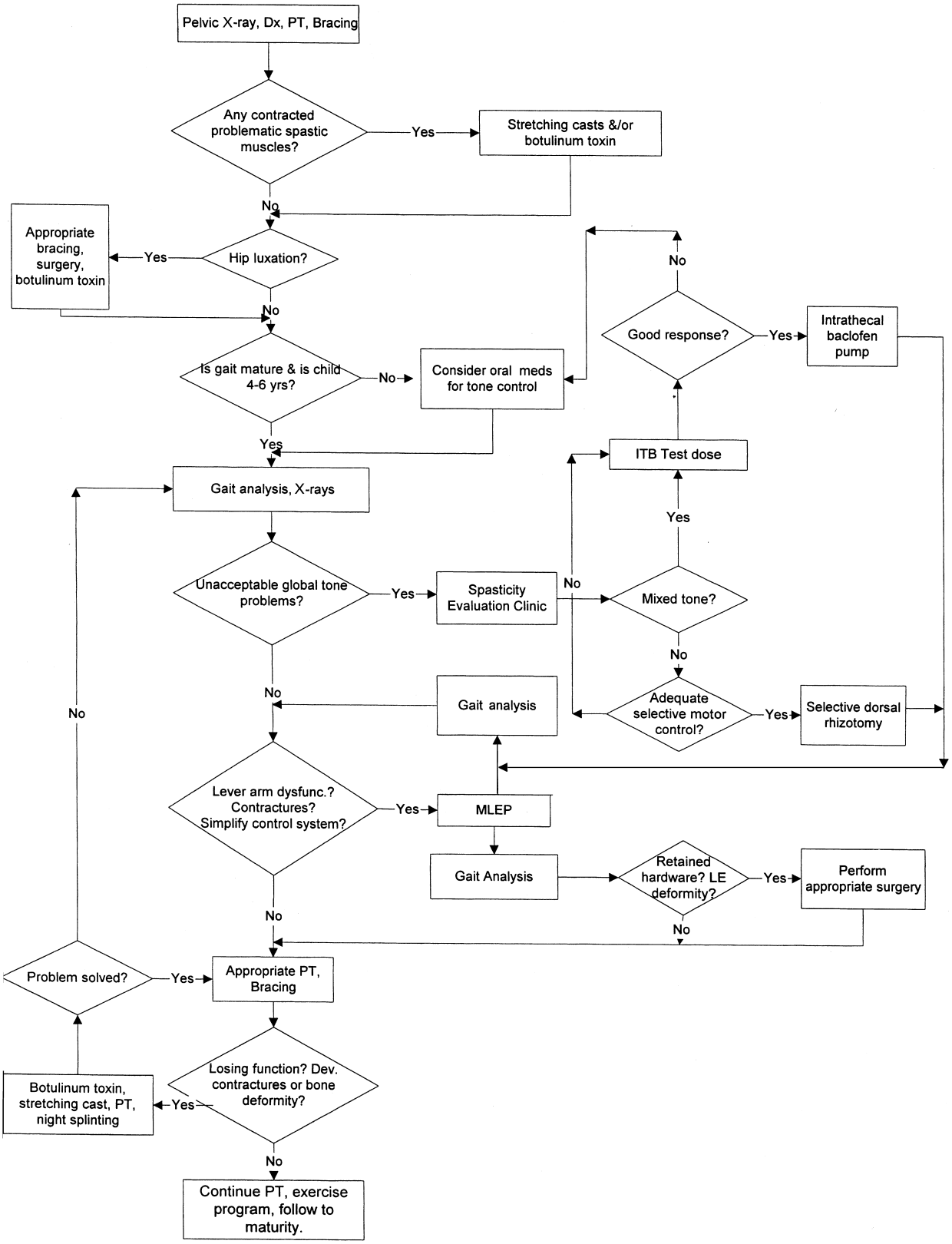

FIG. 7. The current treatment algorithm for a young child with spastic diplegia. Diamonds indicate decision points and rectangles indicate specific treatments. Dx, Diagnosis; PT, physical therapy; LE, lower extremity; ITB, intrathecal Baclofen; MLEP, multiple lower extremity surgeries. MLEP is our term for the procedure in which all muscle contractures and lever-arm dysfunctions (hip subluxation, femoral anteversion, tibial torsion and/or foot deformities) are corrected during the course of a single surgical procedure. This is usually accomplished by two surgeons operating simultaneously, with one surgeon correcting all deformities on the patient's left side while his colleague corrects all deformities on the patient's right.

gait. Consequently, orthotic needs are different. Frequently, less rigid, posterior leaf-spring AFOs can be used. Spasticity hinders strengthening programs for children with cerebral palsy, and insufficient muscle strength can be a major cause of ongoing disability. As a result of spasticity reduction, physical therapy for strengthening may now be more beneficial than in the past.

If the treating physician remembers that moment-generating capability is the key to good musculoskeletal function, it will allow him/her to identify not only muscle strength deficiencies, but also lever-arm dysfunction. Knee extensor lag and plantarflexor moment insufficiency can both be debilitating causes of crouch in the adolescent.

CASE STUDY

BM was born 6 weeks premature with a birth weight of 2.2 kg. At 18 months of age, the diagnosis of asymmetric diplegic cerebral palsy (left side more affected) was made. The patient began walking at age 2. By age 3 years 8 months, she was an independent community ambulator with bilateral solid AFOs, at which time her gait dysfunction was evaluated in the gait lab. This analysis underscored the adverse effects of both lower extremity orthopaedic deformities and multilevel lower extremity spasticity on stance phase stability, swing phase clearance, and inappropriate pre-positioning of the foot for initial contact. She had toe–toe initial contact on the left and foot-flat on the right, with in-toeing bilaterally.

The patient underwent selective dorsal rhizotomy from L1 to S2 (25% right and 44% left) at age 4 years 3 months. Subsequent orthopaedic procedures included bilateral femoral derotational osteotomies, bilateral gastrocnemius recessions (Strayer), and left os calcis lengthening at age 4 years 11 months. Subsequently, she had bilateral femoral hardware removal and left posterior tibialis lengthening (Frost procedure) at age 5 years 11 months. Figure 1 shows the left lower extremity sagittal plane kinematics.

Posttreatment, the family felt that BM was: 1) able to walk further with better endurance; 2) better able to keep up with her friends; and 3) now able to run. In addition, she had improved balance, as evidenced by being able to ride her bicycle. Her oxygen cost of walking had decreased 55% (from 2.55 times normal to 2.0 times normal). The family was extremely satisfied with the results. Pertinent findings on gait analysis include improved hip extension, elimination of crouch, improved knee range of motion during gait, improved knee extension in preparation for initial contact, and correction of equinus during stance and drop foot in swing (Fig. 1).

OUTCOME ANALYSIS

In 1999, we undertook an outcome analysis study of the treatment of a group of ambulatory children with cerebral palsy. The goal of the study was to objectively document treatment outcomes in spastic diplegic/triplegic cerebral palsy. Technical, functional, and patient/parent satisfaction outcome criteria proposed by Goldberg (5) were used.

The test group consisted of 32 individuals with spastic diplegia or triplegia. Criteria for admission to the study included: 1) independent ambulation without assistive devices; 2) no previous surgery to modify lower extremity function; and 3) all subsequent orthopaedic surgery provided by one of the two authors. Individuals who met the criteria for this study were placed into one of three groups depending on treatment: 1) orthopaedic surgery only; 2) spasticity reduction only; and 3) spasticity reduction and orthopaedics.

Technical assessment included metabolic energy expenditure and normalcy index (9). Functional assessment included a questionnaire developed at Gillette Children's Specialty Healthcare (7). The patient/parent satisfaction was reported by assessing the overall feeling toward the outcome of intervention using the following scale: 1) extremely satisfied; 2) satisfied; 3) neutral; 4) dissatisfied; 5) extremely dissatisfied.

The results of the evaluation of technical outcome are indicated in Table 2. Significant improvements were seen by the two measures of technical outcome. The greatest improvements occurred in the group that underwent treatments to reduce spasticity and correct orthopaedic deformity.

Function is assessed using a 10-level, parent-report walking scale ranging from unable to walk to normal ambulation. Results are presented in Table 3. The results were mixed in the children in the group undergoing orthopaedic surgery. Some lost ambulatory function; however, in several of these children, treatment was still in progress because they were awaiting selective dorsal rhizotomy. Consequently, treatment could not be considered complete in these children. Children who underwent either spasticity reduction or combined treatment consistently showed no loss of function and most were improved.

The ability of the child to accomplish 22 community functional mobility skills (such as stair climbing,

TABLE 2. *Technical outcome*

	Oxygen cost	Normalcy index
OSO ($n = 17$)	Improved (↓ 24%)	Unchanged
SRO ($n = 7$)	Improved (↓ 43%)	↓ 25%
SR + OS ($n = 8$)	Improved (↓ 62%)	↓ 30%

The technical outcome in each of the three groups: 1) orthopaedic surgery only (OSO); 2) selective dorsal rhizotomy only (SRO); and 3) both rhizotomy and orthopaedic surgery (SR + OS). *n*, the number of subjects in each group.

TABLE 3. *Functional outcome*

	Improved	Unchanged	Decreased
OSO ($n = 17$)	(6/17)	(7/17)	(4/17)
SRO ($n = 7$)	(6/7)	(1/7)	(0/7)
SR + OS ($n = 8$)	(6/8)	(2/8)	(0/8)

Functional outcome using the 10-level, parent-report walking scale (ranging from unable to walk to normal ambulation) in each of the three groups: 1) orthopaedic surgery only (OSO); 2) selective dorsal rhizotomy only (SRO); and 3) both rhizotomy and orthopaedic surgery (SR + OS). *n*, the number of subjects in each group. Notice that the functional level of walking actually decreased in four of the patients who had only orthopaedic surgery, whereas this never occurred in the groups that included selective dorsal rhizotomy.

running, stepping up/down over a curb or other objects, getting on or off the bus or escalator, hopping, skating, and bicycling) is also determined by parent report. The number of skills that a child could accomplish before and after intervention was determined. The results are indicated in Table 4. On average, skills are added. Again, combined treatment led to the greatest improvements.

Technical and functional outcomes correlate well. Although the number of children in each group is small, the results suggest that the combined approach to treatment may be better than either modality used alone.

Patients and families report a high level of satisfaction, with 16/17 in the orthopaedic surgery only group, 7/7 in the spasticity reduction only group, and 8/8 in the spasticity reduction and orthopaedics group being satisfied or extremely satisfied. Even though patients and families are quite pleased with the outcome of the intervention chosen, one can see that this scale of patient satisfaction is not useful as a discriminating measure between groups because it was unable to differentiate between better and poorer outcomes.

TABLE 4. *Functional outcome*

	Average number of skills added (+)/lost(−)
OSO ($n = 17$)	+2.6
SRO ($n = 7$)	+4.6
SR + OS ($n = 8$)	+6.0

Functional outcome using the average number of functional skills gained in each of the three groups: 1) orthopaedic surgery only (OSO); 2) selective dorsal rhizotomy only (SRO); and 3) both rhizotomy and orthopaedic surgery (SR + OS). *n*, the number of subjects in each group. The 22 functional skills include: walk carrying an object, walk carrying a fragile object or a glass of liquid, walk up and down stairs using the railing, walk up and down stairs without needing the railing, steps up and down a curb independently, runs, runs well including around a corner with good control, can take steps backwards, can turn and maneuver in tight areas, able to get on/off the bus independently, jump rope, jumps off a single step, hops on right foot, hops on left foot, steps over an object right foot first (e.g., a toy left on the floor), steps over an object left foot first, kicks a ball with right foot, kicks a ball with left foot, rides two-wheel bike, rides three-wheel bike, ice skates or roller skates, rides an escalator (stepping on/off by himself/herself). Note that all groups gained skills, but those with combined tone reduction and correction of lever-arm dysfunction gained the most.

Our current opinion is that it should be beneficial to go back and critically study the group of children who did not improve because, from the standpoints of both cost and morbidity, it is important to know who not to treat. However, technical outcomes such as this should allow more accurate comparison of the results of different treatment methods. In the long term, the use of critical outcome parameters such as these should enable surgeons to reduce the cost and improve the end result of treatment. It should also have the beneficial effect of making treatment of these complex neuromuscular conditions more predictable.

CONCLUSION

This article was written with the goal of illustrating the current methodology for treating children with ambulatory problems owing to cerebral palsy at our hospital and clinics. Gait analysis has played and continues to play a crucial role in many aspects of this scheme including education to better understand normal and pathologic gait, the evaluation of the unique problems for each individual patient to improve individual decision-making, and assessment of outcome following major interventions. Prior to computerized gait analysis, there was no good objective measurement tool for the dynamic aspects of movement.

The resulting treatment methodology is firmly based in the critical role of team management. The team is comprised of pediatric specialists including physical therapists, orthotists, members of the gait analysis team, neurosurgeons, physiatrists, and orthopaedic surgeons. Each of these specialists offers a unique perspective that enhances the development of a comprehensive evaluation and treatment program for each individual patient. The program is broadly based on two general concepts, the management of spasticity and lever-arm dysfunction, which are central to this assessment and treatment methodology.

It is true that some aspects of specific treatments outlined in this article have not been critically evaluated in double-blinded, randomized, controlled clinical trials. That level of rigorous evaluation is not clinically realistic because we feel it is the combination of multiple, simultaneous interventions that is necessary to achieve the best outcome. The use of gait analysis as an objective measurement tool along with concurrently gathered functional outcomes data will allow the benchmarking of this treatment

methodology against others, and will provide the basis for future progress in evaluation and treatment for this interesting and challenging group of patients.

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