People With Cerebral Palsy: Effects of and Perspectives for Therapy

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SUMMARY

The movement disorder of cerebral palsy (CP) is expressed in a variety of ways and to varying degrees in each individual. The condition has become more complex over the last 20 years with the increasing survival of children born at less than 28 to 30 weeks gestational age. Impairments present in children with CP as a direct result of the brain injury or occurring indirectly to compensate for underlying problems include abnormal muscle tone; weakness and lack of fitness; limited variety of muscle synergies; contracture and altered biomechanics, the net result being limited functional ability. Other contributors to the motor disorder include sensory, cognitive and perceptual impairments. In recent years understanding of the motor problem has increased, but less is known about effects of therapy. Evidence suggests that therapy can improve functional possibilities for children with cerebral palsy but is inconclusive as to which approach might be most beneficial. The therapist requires an understanding of the interaction of all systems, cognitive/perceptual, motor, musculoskeletal, sensory and behavioral, in the context of the development and plasticity of the CNS. It is necessary to understand the limitations of the damaged immature nervous system, but important to optimize the child's functional possibilities.

KEYWORDS

impairment, physiotherapy, intervention, disability, motor function

INTRODUCTION

Cerebral palsy (CP) has been defined as an umbrella term covering a group of persistent non-progressive, but often changing, disorders of posture and movement secondary to lesions or anomalies of the brain arising in the early stages of development (Mutch et al., 1992; Aicardi & Bax, 1998). Any consideration of the effect of cerebral palsy on a person and the possibilities for therapy intervention must recognize that CP is in fact a variety of conditions (Rosenbloom, 1995; Badawi et al., 1998). The type and severity of the condition in an individual person may depend on factors such as the size, location, and timing of the brain lesion (Forssberg et al., 1999). While the commonly used definitions of CP emphasize the postural and motor difficulties encountered by the person (Mutch

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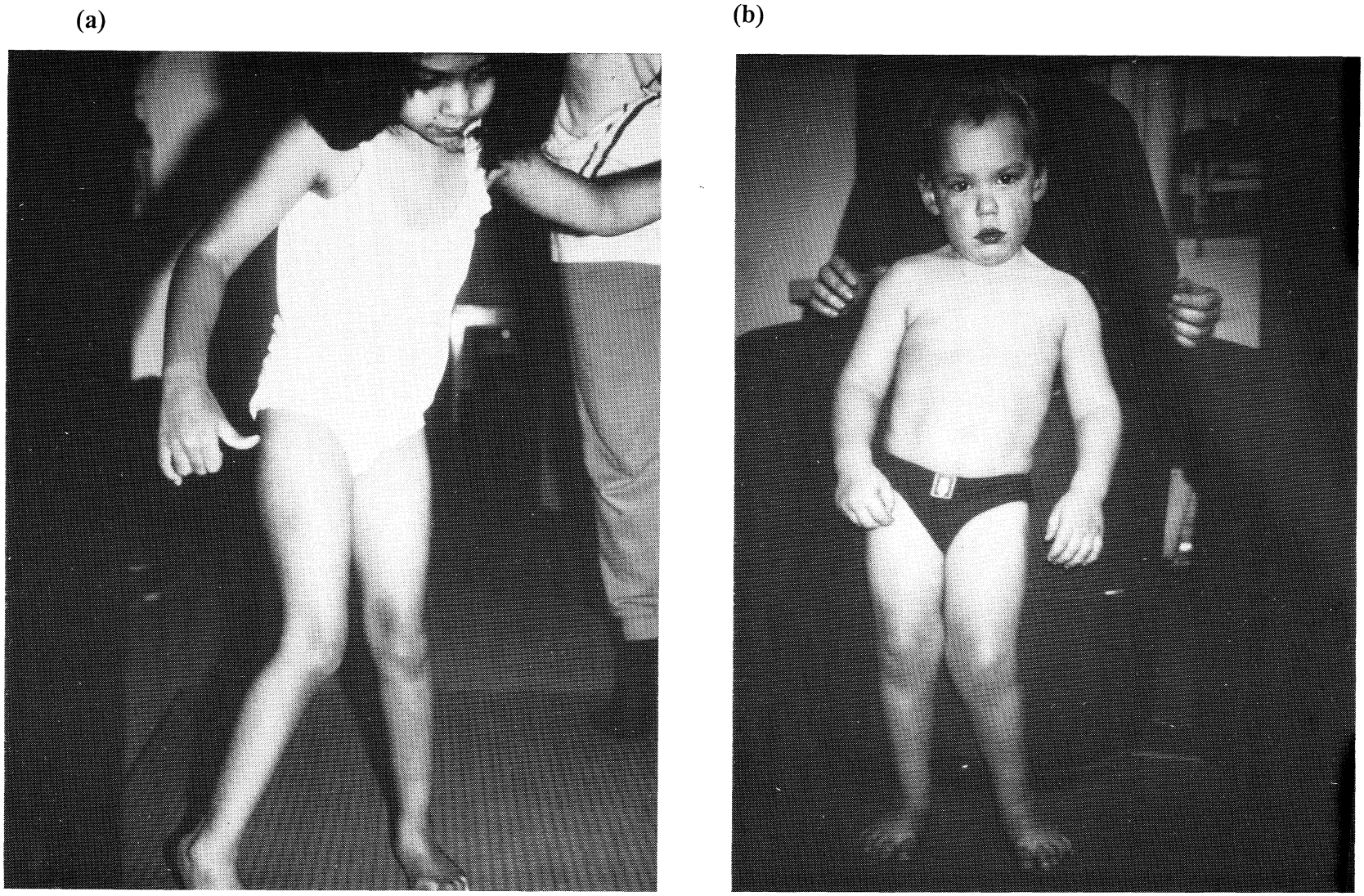

Fig. 1: (a) This child shows the typical posture of a child with spastic diplegia, with a flexed posture which is more apparent on the right side. She also shows the typical equinovarus deformity distally. (b) This child also has spastic diplegia but due to his extreme prematurity has truncal instability which results in a lack of alignment and varus foot deformities.

et al., 1992; Aicardi & Bax, 1998), there are usually other primary factors which contribute to the movement disorder, such as sensory, perceptual, cognitive, and musculoskeletal impairments. A child may show signs of spasticity, dyskinesia (athetosis and ataxia), or both, which can have different topographical distributions. Total body involvement with equal involvement of the upper and lower limbs, or mainly affecting the upper limbs, is classified as quadriplegia, but if the lower limbs are predominantly affected, then a classification of diplegia is given. If the neural lesion is unilateral and only one side of the body is affected, the diagnosis is hemiplegia. This results in a range of abilities, from the child who is able to participate in all activities of daily life to the child who has a severe disability and is totally dependent for all needs. Although the brain lesion is static, the condition itself is progressive as a result of changes associated with nervous system maturation, growth, and experience. There have been many attempts at classifying cerebral palsy (Bax, 1962; Ingram 1984; Palisano et al., 1997; Aicardi & Bax, 1998), but unfortunately there is no one accepted classification. The most recent classification by the World Health Organization (ICIDH-2, WHO, 1998) describes disability in terms of impairment, activity limitation, and participation restriction. This may prove to be a useful classification as it considers the child not only as an individual but also in the context of the different environments in which the child needs to participate.

Despite small fluctuations, the incidence of CP has remained around 2.5 live births per thousand (see Fig. 2 in Hagberg et al., 1996). However, there have been changes in the epidemiological pattern and clinical signs. Changes in epidemiology have been well documented by several authors, notably Hagberg's group in Sweden (Hagberg et al., 1993; 1996) and the group in Western Australia (Dale & Stanley, 1980; Stanley & Watson, 1992). In particular, the increasing survival of the extremely preterm infant (less than 28 to 30 weeks gestational age) has resulted in a changed clinical picture of cerebral palsy (Hagberg & Hagberg, 1996).

The common pathology of the infant born at around 28 weeks gestational age is periventricular leucomalacia (PVL) and usually results in spastic diplegia, the clinical picture often made more complex by the presence of specific visual and perceptual problems. If the lesion is more extensive and extends into sub-cortical areas, the diagnosis is usually that of spastic quadriplegia, often associated with significant visual, cognitive, and perceptual problems in addition to seizures. This is not surprising. An increasing body of evidence suggests that children born at less than 28 to 30 weeks gestational age, with extremely low birth weight and without known pathology, have impairment of gross and fine motor skills (Burns et al., 1999). Thus, the starting point of development for a child who subsequently develops CP is already less than optimal. There are many reports of impairments of visual, perceptual, and cognitive ability in this group (Cioni et al., 1997; Fedrizzi et al., 1998; Cioni et al., 2000).

Less information is available regarding changes in clinical presentation. However, observations by therapists suggest that the increase in survival of extremely preterm infants or severely asphyxiated full-term infants has resulted in children who have low tone and weakness proximally, especially in the trunk, which is usually accompanied by marked hypertonia of the limbs (Mayston & Murray, 1999). This results in significant truncal instability, poor alignment of body parts, and a limited postural repertoire (Hadders-Algra et al., 1999a). In contrast, children of later gestational age, who have potentially adequate trunk stability, have the possibility to develop the appropriate pattern of postural reactions (Hadders-Algra et al., 1999a). An example is given in Fig. 1. The child in Fig. 1a is typical of a child born at 34 weeks gestational age and shows the classic picture of a

child with spastic diplegia. This child has marked stiffness around the pelvis and in the lower limbs and internal rotation of her hips. This is different from the child in Fig. 1b, whose legs are also more affected than his arms but who demonstrates poor alignment of body parts with no consistent postural asymmetry or internal rotation of the hips. The main reason for this difference is the truncal instability and weakness with accompanying hypermobility and instability of the pelvic and shoulder girdles. Differences are also apparent distally: the child showing the typical picture of spastic diplegia has bilateral equinovarus deformities, whereas the child who demonstrates truncal instability has valgus deformity of his feet due to the co-existence of hyper- and hypotonia, the latter allowing for hypermobility of the ankle and forefoot. Truncal instability in these children also results in difficulty with manipulative skills because of insufficient proximal stability, despite having good dexterity. The combination of proximal hypotonia and hypertonia of the limb girdles and limbs presents a challenge for training postural activity, in addition to the management of musculoskeletal problems, especially the feet, spine, and hips.

PATHOPHYSIOLOGY OF THE MOVEMENT DISORDER OF CEREBRAL PALSY

There have been no systematic studies of the pathophysiology of CP, but various studies using neurophysiological techniques and kinematic analysis give some insight into the mechanisms underlying the sensorimotor deficits encountered in children with CP. These deficits often indicate that the child with CP retains characteristics of the early central nervous system (CNS). The following discussion describes some of the research findings of what is known about the pathophysiology of the movement disorder of CP.

Lack of cortical control of spinal motoneurone pools

Studies utilizing transcranial magnetic stimulation (TMS), have shown that the corticospinal projection from the damaged motor cortex to the motoneurone pools of the distal upper limb muscles is sparse or absent (Carr et al., 1993; Mayston et al., 1995). Cortical control has also been investigated using cutaneomuscular reflexes (CMRs), which provide a means of investigating activity in spinal and transcranial pathways (Jenner & Stephens, 1982). This triphasic response to stimulation of the digital nerves has shown in young children and those with spastic CP, that the spinal response (E1) predominates (Evans et al., 1987; Gibbs et al., 1999b). This indicates a lack of cortical control, thus explaining in part the impairment of voluntary and postural activity found in this group of children. The lack of cortical control of movement will also result in an impairment of feedforward or anticipatory control of both postural and task related activity (Eliasson et al., 1992; Brogren et al., 1996). In particular, the absence or paucity of the corticospinal projection will result in limited ability to perform relatively independent finger movements and therefore difficulty in performing effective manipulative skills. It is well known that the corticospinal projection is essential for fine hand coordination (Carr et al., 1993; Lemon, 1993; Galea & Darian-Smith, 1997).

Reorganization of corticospinal projection

Carr et al. (1993) have shown in children with spastic hemiplegia and obligatory mirror movements that the corticospinal projection from the intact hemisphere branches to innervate motoneurone pools of homologous upper limb muscle pairs. This reorganization was found only in children who had been damaged early (less than 24 weeks

gestational age) and provides evidence for the ability of the CNS to reorganize in certain conditions. A similar reorganization of the corticospinal tract has also been reported to occur in children with spastic quadriplegia associated with very preterm birth (Mayston et al., 1995). A bilateral corticospinal projection, if branched will result in simultaneous activity of both hands. While this may be of functional advantage in some cases to allow opening of the hemiplegic hand in the absence of control from the damaged hemisphere, such bilateral activity will interfere with bimanual tasks when different action of the left versus the right hand is required. In the case of an unbranched, but nevertheless bilateral projection, the functional outcome will be similar, although the involuntary activity in the children with spastic quadriplegia did not appear to be as strong as in the case of children with spastic hemiplegia with branched corticospinal axons. No doubt this was due to the already limited function of the hand in which the mirrored activity occurred.

Lack of synchronization of synergistic muscles

It might be expected that the mass movements observed in young children and those with CP might be produced by the synchronous activity of many muscles. Indeed studies of reflex responses in young children and those with CP have shown that a single tendon tap results in the simultaneous activation of groups of muscles (O'Sullivan et al., 1991; Leonard et al., 1995). It was hypothesized that such activation resulted from monosynaptic connections between the muscles tested. If this were the case, then this shared input should be able to be demonstrated using cross-correlation analysis (Sears & Stagg, 1976). Gibbs et al. (1997) used cross-correlation analysis to determine if the apparently synchronous activity of muscle pairs was produced by shared synaptic input to the motoneurone pools innervating these muscles. The presence of flat correlograms (i.e. no central peaks) showed that the CNS activated the motoneurone pools independently in young children and those with CP (Gibbs et al., 1997; 1999a). Skilled action results from synchronous activity produced in the CNS by shared synaptic input to synergistic muscles (Bremner et al., 1991; Stephens et al., 1999), and follows a developmental sequence (Gibbs et al., 1997).

Lack of anticipatory motor control

It is known that children with CP have difficulty in adapting to different loads to the fingers and performing efficient manipulative skills. This can be due to a lack of cortical control, impaired sensory feedback or both (Eliasson et al., 1991; 1992; 1995; Gordon & Duff, 1999). Studies of children during development have confirmed the developmental aspect of these abilities, suggesting that children with CP whose immature nervous system has been damaged may retain such characteristics. (See Gordon & Forssberg. 1997, for a review).

Interaction between agonist and antagonist muscle pairs

In the adult, antagonistic muscles can either co-contract to stabilize a joint or can act reciprocally, as occurs when a limb moves or exerts force about a joint. In young children less than 5 years of age and those with spastic CP, agonist and antagonist muscles co-contract and rarely work reciprocally (Berger et al., 1982; Forssberg, 1985; Brogren et al., 1998). The presence of co-contraction of agonist-antagonist muscle pairs of the upper and lower limbs is well documented in children with spastic CP and is thought to be due to a deficit in the reciprocal inhibitory mechanism. The most likely explanation for this is a lack of facilitation of the Ia inhibitory

interneurone by the corticospinal projection (Leonard et al., 1990; Mayston et al., 1996; 1998; O'Sullivan et al., 1998). Interestingly, for the trunk muscles, the developmental sequence is the opposite, with the dorsal and ventral trunk muscles changing from a pattern of reciprocal activity to co-activation to give the required trunk stability for postural control and independent limb movements for postural and manipulative skills (Hirschfeld & Forssberg, 1994).

Postural control

The presence of co-contraction of agonist and antagonist muscle pairs has been described as one aspect of the inability of children with spastic cerebral palsy to develop adequate postural control (Berger et al., 1982; Leonard et al., 1991; Brogren et al., 1998). It has also been shown that the patterns of postural activity may be disturbed or inconsistent or may not be recruited in the appropriate temporal sequence for efficient postural adjustment (Nashner et al., 1983; Brogren et al., 1996; Hadders-Algra et al., 1999b).

IMPAIRMENTS OF THE PERSON WITH CEREBRAL PALSY

While these research studies have given some insight into possible mechanisms underlying movement disorder in children with CP, therapists are usually more concerned with the impairments which underlie the functional difficulties encountered by the child. Furthermore, the most recent WHO classification (ICIDH-2, 1998) is based on impairments. Most therapists work predominantly at an impairment level when trying to improve the functional possibilities of the child. The most commonly described impairments in CP include the following:

- *Muscle tone*: the assessment of reflexes and muscle tone as resistance to passive movements are an integral part of the neuropediatrician's assessment (Mercuri & Dubowitz, 1999). Therapists also place much emphasis on the role of muscle tone in the control of movement, an idea that was introduced and emphasized by Bobath (Bobath & Bobath, 1984). Tone is probably more complex than previously thought and comprises both neural and non-neural elements (see Dietz, 1999, for a review). The significance of so-called primitive reflexes is questionable and although their assessment maybe useful for diagnosis, they are of no value to the therapist in understanding the functional difficulties of the child.
- *Muscle weakness*: Until recently it was thought that muscle weakness was secondary to problems of abnormal muscle tone, an idea proposed by Bobath (1985). However, it has now been shown that muscle weakness can be a significant problem for the child with CP (Giuliani, 1992; Damiano & Abel 1998) and can be a major cause of apparent increases in hypertonia, especially as the child grows and muscles become less extensible (Mayston, in press). Although muscle weakness is increasingly being recognized as a significant impairment in children with CP, little seems to be done to specifically strengthen weak muscles in most pediatric therapy departments.
- *Loss of selective movement*: is often quoted as a problem by therapists (Wilson-Howle, 1999). The variety of movement patterns found in healthy children and adults contrasts to the limited movement options available to the child with CP. For example, some children can move efficiently on the floor, but have difficulty functioning in more challenging anti-gravity positions due to lack of postural reactions, effort, increased stiffness, or instability which limits their available movement options.

The neural lesion results in mass patterns of muscle activation preventing the selective activity of certain body parts. For example, overuse of the sound side by the child with hemiplegia can result in an increase in stiffness and reduced mobility on the affected side, thus interfering with the ability to perform bimanual tasks.

- *Co-contraction of agonist and antagonist muscle pairs*: As previously discussed, there are many reports of the presence of co-contraction of agonist and antagonist muscle pairs in children with spastic cerebral palsy, although it must be recognized that altered biomechanics may be in part responsible (Woollacott & Burtner, 1996).
- *Postural control*: It has been shown that children with CP have altered patterns of muscle activation for postural adjustment. For example, rather than using the adult pattern of distal to proximal activation of muscle activity for postural adjustments in standing, children with spastic diplegia demonstrate a proximal to distal sequence (Nashner et al, 1983; Brogren et al, 1996). However, Hadders-Algra et al, (1999b) found that the basic organization of responses in children who developed spastic CP were intact although their modulation was deficient, whereas those with spastic-dyskinetic CP showed abnormalities of the basic organization of postural adjustments. Therapists, however, usually divide the well-integrated postural responses into component reactions and assess the presence of righting (for alignment), equilibrium (for stability) and protective reactions (support by the limbs when displaced too far from the centre of gravity), rather than assessing postural control in a more appropriate task specific context.
- *Musculoskeletal problems*: In the child with CP, minimization and management of muscle contracture forms a major part of therapy intervention. Most children with CP have altered muscle length to some degree, either hypo-extensibility or in the case of some muscle groups, hyperextensibility. This of itself will result in altered force generation, as it is well known that muscle generates the most effective force at mid-range. The resulting musculoskeletal problems and altered bio-mechanics have been described by several authors (Bax & Brown, 1985; Bleck, 1987; Tardieu et al., 1988; Rose & McGill, 1998). Another factor contributing to force production is muscle fiber type. It is known that the distribution of muscle fiber types can be altered in spastic cerebral palsy, such that there is a predominance of Type 1, slow twitch, fatigue resistant fibers (Ito et al., 1996). This predominance of Type I fibers may result in static rather than the dynamic or fast phasic activity required for quick postural adjustment and powerful movements.

Sensory impairment in CP is often difficult to determine. There may be a primary sensory deficit, or problems of sensory processing and delay. Standardized tests are often difficult to perform because these mostly require good manipulative skills and cognitive ability, both of which may be significantly impaired in children with CP.

The degree of perceptual and cognitive impairments varies in different children, but in particular, specific spatial and visual perceptual difficulties can be the main problem for a child with CP. Fear associated with a spatial-perceptual problem may cause an apparent increase in spasticity. Reducing spasticity in this case will have little long-term effect and, in fact, may increase the insecurity of the child.

Taken together, some or all of these impairments are present in each child with CP and result in functional limitations to varying degrees.

PERSPECTIVES FOR THERAPY

Given the diversity of the problem, it is not surprising that evidence to support the positive effects of intervention is lacking (Hur, 1995; Weindling, 2000). Randomized controlled trials can be difficult to carry out, both because of small sample sizes and for ethical reasons (Hur, 1995; Reddihough et al., 1998), and most studies concentrate on the effects of early intervention for the high-risk groups (Weindling, 2000). Overall results are inconclusive. Despite this, therapy is widely advocated and desired, and there are many therapy approaches to the management of CP, the most common being Bobath, Conductive Education (Peto) and Vojta (in Europe). Others include Doman-Delacato (Patterning), Sensory Integration, Movement Opportunities Via Education (MOVE), and adjuncts such as hydrotherapy and hippotherapy, in addition to alternative therapies for example, acupressure and osteocraniosacral therapy.

There have been some attempts to evaluate effectiveness of therapy intervention (Palmer et al., 1988; Bower et al., 1992; Bairstow et al., 1993; Bower et al., 1996; see Hur, 1995, and Weindling, 2000, for a review). However, little or no evidence is available to show that therapy is effective or that one approach is more beneficial than another. Despite this, therapy programs are an integral part of the management of the child with CP. The other question often asked is how much and how soon, again for these questions there are no definitive answers (Bower et al., 1996; Reddihough et al., 1998; Weindling, 2000).

On the basis of what is known about CNS changes during development, it would appear that early therapy should be effective in minimizing the negative effects of CP, at least in some children. In addition, greater knowledge of the underlying mechanism of CP and the possibilities for early detection should enable more effective management of the condition (Prechtl et al., 1997). The concept of neuroplasticity is also an attractive factor for promoting the intervention process (Wigglesworth, 1989). Given that experience seems to be important in shaping the function of the developing nervous system (see Hadders-Algra, 1997 and Hadders-Algra, this issue), therapy should have a significant effect on the quality of outcome. Finally, the availability of measurement tools gives the possibility of determining what might be the most effective intervention. The scene seems to be set for therapy to have a positive effect—why then is there so little evidence to support the benefits of therapy programs? In addition to recognizing the complexity of CP, it seems necessary to examine what it is that therapists do.

The main aim of therapy for the child with CP should be to improve the quality of life for the individual person and their family and to prepare for improved quality of life during adult years. Depending on the age of the child and severity of the disability, three general aims can be identified.

1. Increase or improve the skill repertoire
2. Maintain functional level
3. General management and minimization of contractures and deformities.

How do therapists achieve these aims? Rather than examining different therapy approaches, I will discuss four aspects of commonly applied therapy intervention.

REDUCTION OF THE EFFECTS OF ABNORMAL MUSCLE/POSTURAL TONE

Most assessments of sensorimotor function of children with CP, either by the pediatrician, therapist or orthopedic surgeon, include testing of muscle tone and reflexes. Bobath (1984) recognized the over-emphasis on reflexes as an explanation for the atypical movement patterns observed in children with cerebral palsy. Fortunately, it would seem

that the majority of therapists working with children with cerebral palsy have discarded the concept of released tonic reflexes as an explanation for spasticity. However, therapists who use the Bobath approach consider tone to be an integral component of motor control. But what is tone? It is necessary to understand normal tone in order to appreciate the nature of any deviation from the so-called norm. The original idea, proposed by Sherrington (1906) and adopted by Bobath (1984), that tone is *exclusively* the result of tonic reflex activity is now outdated (see Mayston, in press). The understanding of tone is further complicated by the emphasis on postural tone as described by Sherrington (1906). Human upright posture requires various degrees of muscle activity for its maintenance, although many limb muscles can relax completely during upright postural control. Despite this, these muscles are ready to be activated to counteract any loss of balance or for performing a required task.

It is more helpful to view tone as comprising both neural and non-neural components (Basmajan et al., 1985; Lin et al., 1994). The nervous system obviously influences the activity of muscles via spinal reflex pathways and descending controls (see Dietz, 1999, for review). But it is clear from the neurophysiological and biomechanical models of motor control that visco-elastic properties of the muscles themselves are important contributors to tone (Lin et al., 1994). In this respect, therapists need to be cognizant of the complementary aspects of neurophysiology and biomechanics. Tone, whether normal or abnormal, needs to be understood as being composed of both the active contraction and the visco-elastic properties of muscle. In this respect, the definition by Bernstein (1967), which describes tone as a state of readiness, seems a useful description. Different individuals can have differing states of readiness, according to the sum of the activity of the muscle and its visco-elastic properties, as do patients with movement disorder. For example, the person with hypotonia has a reduced state of readiness, whereas the person with spasticity/hypertonia may be said to have an increased state of readiness. If tone is fluctuating as found in children with athetosis, the state of readiness is unpredictable and constantly changing.

The therapist should ask this question: Am I managing spasticity, hypertonia, or both? It is necessary to determine whether stiffness is due to a lack of power in anti-gravity extensor muscles and associated changes in visco-elastic muscle properties which has resulted in contractures and apparently increased tone (resistance) over time, or if it is due to a an increase in velocity dependent hyperreflexia, which is the classical and universally accepted definition of spasticity and also produces resistance to movement (Lance, 1980). Careful assessment of what is true spasticity as opposed to weakness, loss of dexterity, and contracture (stiffness) should be essential for the appropriate intervention to be applied and may require specific testing to be accurately determined, for example, using EMG recordings. The concept of positive and negative symptoms is useful in understanding that spasticity is often only a small element in the multiple factors that contribute to the client's movement problems (see Carr & Shepherd, 1998, for a review).

An understanding of tone in this way enables a more rational attitude as to what intervention is most appropriate and what therapy might achieve. Can the therapist reduce hypertonia? The literature reveals that there are many ways that spasticity can be reduced. For example, Botulinum toxinA (Cosgrove et al., 1994), surgical dennervation (Bleck, 1987), dorsal rhizotomy (Peacock & Staudt, 1990; Giuliani, 1992), neuromuscular stimulation (Carmick, 1995), and biofeeedback (O'Dwyer et al., 1994). Therapy techniques such as 'inhibitive' casting (Law et al., 1991; Chakerian & Larson, 1993; Hinderer et al., 1988), the use of

orthoses (Cusick 1990), working for more normal patterns of movement (Bobath, 1984), stretching (Tremblay et al., 1990), and stretch via weight bearing (Walshe et al., 1994), have also been used to reduce the effects of so-called spastic muscles. However, the therapy techniques devised to reduce 'spasticity' are more likely to influence the non-neural rather than the neural aspects of hypertonia. Tone-reducing casts, muscle stretching, and stretch through weight bearing are ways that stiff muscles can be lengthened, thereby allowing other muscles to work more efficiently or the stretched muscles themselves to be at a more appropriate length for efficient activation. Handling by the therapist can reduce the abnormal reflex activity produced by the firing of hypersensitive muscle spindle and golgi tendon organs and via stretching of stiff muscles can obtain a better biomechanical advantage for more efficient muscle activation. However, it is only by activating the person in optimal and useful ways that any *long-lasting* reduction of the effect of spasticity can be achieved (Mayston, 2000).

It is unfortunate that the word inhibition is so ingrained into the physiotherapy literature, and it would be preferable to remove it from the therapy strategy vocabulary. The word inhibition poses many problems. There are many examples of inhibition in the CNS; for example, reciprocal Ia inhibition, lateral inhibition, Renshaw cell inhibition, pre- and post-synaptic inhibition. The term inhibition was introduced by Bobath (1984) to explain tone reduction commensurate with the idea that hypertonia was produced only by abnormal tonic reflex activity. This view can no longer be supported.

Less is known about hypotonic muscle, but certainly for the child who has survived a severe hypoxic delivery at full-term or who has CP associated with extreme prematurity, the presence of hypotonia of the trunk and underlying limb hypertonia presents a management challenge. True hypotonic muscle is difficult to activate, to strengthen, and to gain sustained anti-gravity activity (clinical observation) and for such children may be a limitation to the attainment of truncal stability to allow the training of postural and manipulative skills. In such cases, the use of supportive seating/standing equipment is essential for the development of visual and hand skills in particular. Fluctuating tone, like hypertonia can probably be influenced only by training more efficient performance of functional tasks, although clinical experience suggests that stretching and positioning for improved alignment and stimulation of sustained postural activity can enable a better basis for training such movement. Overall, more objective data are required to understand the role of muscle tone in the control of movement, both normal and abnormal/atypical.

MUSCULOSKELETAL PROBLEMS

Muscle weakness

The preoccupation with management of abnormal muscle tone has resulted in less attention to muscle strength, the thought being that it is secondary to the primary problem of tone. However, it is well established that there is a reduction in cortical output in most cases of CP, thus reducing the voluntary drive onto the spinal motoneurone pool. This lack of descending drive has varying effects. Firstly, there is a lack of facilitation of the Ia inhibitory interneurone that leads to deficits in reciprocal inhibition and may cause over-activity of the antagonist muscle. Secondly, hyperreflexia at rest could be enhanced because of a decreased input to the Renshaw circuit, which influences the sensitivity (the gain) of the alpha motoneurones of agonist, antagonist and synergists. Thirdly, a lack of cortical output onto the motoneurone pool will result in a

reduction in the number of motor units recruited and therefore a decrease in voluntary drive and muscle activation. These are the main reasons that hyperreflexia is found in the passive state, whereas a lack of reflex activity is usually observed on voluntary effort (Ibrahim et al., 1993).

Therapists can probably strengthen muscles to a certain extent by the repetition of movements, such as sit to stand and the use of weight bearing, but it may be of value to address strength in more specific and graded ways. Recent reports show that quadriceps strengthening using resisted exercise in a group of children with spastic diplegia can improve walking efficiency and reduce crouch gait of children with spastic diplegia (Damiano et al., 1995; MacPhail & Kramer, 1995).

Treadmill training has been shown to be successful in adults with hemiplegia and in some patients with spinal cord injury (Hesse et al., 1994; Dietz, 1995). This technique has recently been applied to a group of children with CP who were non-ambulatory and found to improve their ability to transfer (Schindl et al., 2000). The authors conclude that treadmill training with partial body weight support is a promising treatment technique in non-ambulatory children with CP (Schindl et al., 2000), but this and studies of adults suggests that the technique may also be of value to ambulatory children and requires investigation.

Muscle length

Another area of controversy of therapy intervention is the management of muscle length. For the developing child with a neurological impairment this presents two challenges: firstly, that of growth, and secondly, muscle imbalance due to hypertonia and/or muscle weakness, but most likely both. It is known that hypertonic muscle does not elongate during growth as well as healthy muscle (Ziv et al., 1984; Rose & McGill, 1998) and as previously mentioned, children with CP will have muscle weakness to some extent. Of course, there are surgical procedures which can manage the problem of shortened and overactive muscle, and the use of Botulinum toxinA is proving to be helpful in addressing these problems, but how is muscle length best maintained and effects of muscle shortening minimized by the therapist?

Passive stretching has long been advocated as a means of maintenance of muscle length, but according to Tardieu et al. (1988), 6 hours a day is required to achieve this result. This does not seem possible unless other means of stretching, such as the use of orthoses, positioning, and use of equipment are part of the daily routine. In the past it was thought that the use of orthoses were detrimental to muscle tone and should not be used in children with significant degrees of hypertonia, an idea suggested by Bobath in the last century. While this *may* be the case for children with true spasticity, the clinical picture now commonly observed is that of joint hypermobility in conjunction with muscle shortening. In these cases in particular, clinical experience suggests that the judicious use of orthotics and splints as an adjunct to therapy enables improved muscle activity of the unsplinted joints, thus allowing improved overall function. Fortunately therapists have progressed in their understanding and use of splints and orthoses, and lycra garments are now part of the overall management of the child with CP and have been shown to be effective if used judiciously (Burtner et al., 1999). This is exemplified in an example from clinical practice given in Fig. 2. This 4-year-old child, born at 28 weeks gestational age, has a mild spastic diplegia with the right side involved more significantly than the left. Although this child has some spasticity/hypertonia which is most evident distally in the lower limb and in the upper limb on effort, his main problem seems to be instability and weakness around the pelvis and

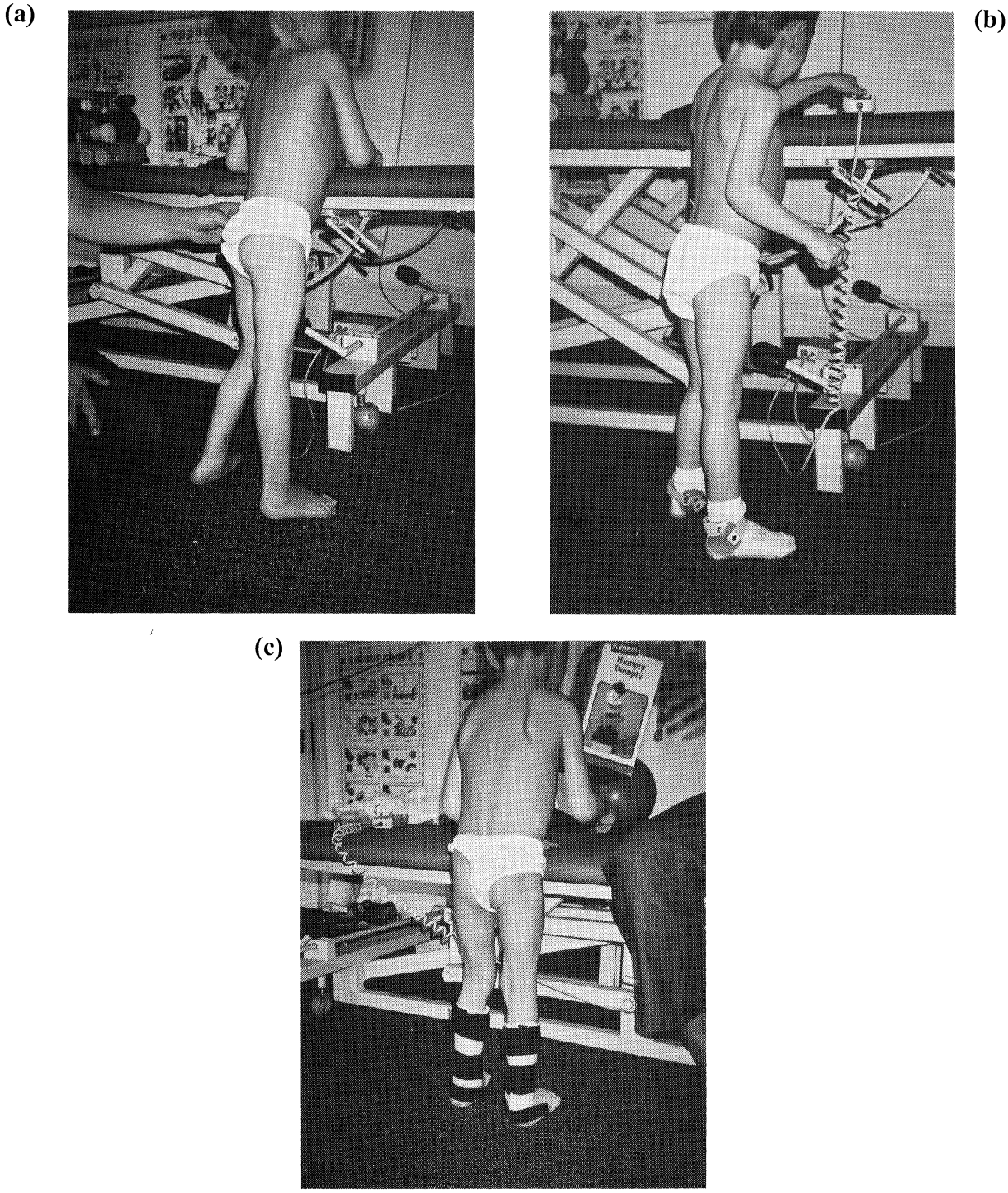

Fig. 2: (a) Without an orthosis this child with an extremely asymmetrical spastic diplegia, shows marked retraction of the right side with difficulty in using the right hand or taking adequate weight through the right leg. This is less marked when dynamic foot orthoses are applied (b). The use of removable splints allows greater symmetry and increased use of the right side for manipulation and weight bearing (c).

trunk. He demonstrates the typical picture of truncal hypotonia and weakness, described in the beginning of this paper as typical for the child with CP which is associated with extreme prematurity. Figure 2c shows that if his foot position can be improved to give a better base for weight bearing, alignment is improved, proximal muscles are more efficiently activated, weight bearing is more evenly distributed, and he can more easily bring the right arm forward for bilateral and even unilateral hand activities. In his case, the ankle needs to be included to prevent hyperextension of his knee and retraction of the whole right side of his body (Fig. 2a). A dynamic ankle foot orthosis (DAFO) in his case was insufficient (Fig. 2b). The removable splint made by the physiotherapist can be used within therapy sessions, and with the addition of an over-shoe such as a light running shoe, can be worn during regular daily activities. However, care must be taken not to wear the splints constantly (or ankle foot orthoses that limit ankle movement), as this can result in reduced activity of calf muscles (Burtner et al., 1999) and may promote atrophy and subsequent reduction in already limited functional ability.

WORKING FOR ACTIVITY IN A FUNCTIONAL CONTEXT

Evidence from studies of animal models and healthy adults show that neural reorganization can occur as a result of specific or altered sensory input (Jenkins et al., 1990; Hamdy et al., 1998) or can be activity driven (see Nudo, 1999, for a review). Therapists use various sensory inputs such as tactile, proprioceptive, and vestibular, to try to improve the sensory control of a child's function. From a motor perspective, therapists attempt through handling techniques, such as stretching, specific activation of muscle patterns, and helping a child to modify the way functional activities are carried out, to promote optimal development of activities of daily life. It is also important to recognize that the CNS is task dependent in its organization (Flament et al., 1993; Ehrsson et al., 2000) and just working to improve patterns of muscle activation will not in itself provide the possibility for learning a new skill. Thus, the idea originally proposed by Bobath that improving patterns of coordination will be of value is limited, unless these patterns are learnt in the appropriate functional context. It may be of some value to give the child the idea of a particular movement, for example hip and knee extension for standing in a position such as supine or prone. But, unless this is then practiced in standing, it is unlikely that the child will achieve the goal of improved standing. Thus the emphasis on preparation as emphasized by Bobath (Bobath & Bobath, 1984) must be carried through into the correct functional context (Mayston, 2000). Unfortunately, many therapists do not place enough importance on the practice of functional activities in their intervention programs. Conversely, some approaches over-emphasize the performance of functional tasks using compensatory activity or not maximizing the child's full potential. This results in task performance with insufficient attention to maximizing biomechanical advantage, such as ensuring that muscles are at their best length for efficient activation, often resulting in the need for unnecessary surgical intervention.

There is some evidence to suggest that training can improve postural activity and automatic stepping activity in healthy infants (Hadders-Algra et al., 1996; Sveistrup & Woollacott, 1998; Yang et al., 1998). It might be supposed that if the child with CP receives adequate training and has sufficient adaptability of the neural structures underlying

these changes, then we could expect that therapy, which promotes such training, should enhance the functional possibilities of the child with CP. Although evidence is limited, several authors suggest that goal-directed therapy programs are of value (Shepherd, 1995; Bowers et al., 1996; Fetters & Kluzik, 1996).

Of interest for the question of activity-driven neuroplasticity and its importance is a strategy known as Constraint Induced Therapy (CIT) for people with hemiplegia, described in both the animal and adult literature. The original work by Taub et al. (1993) with the Macaque monkey has subsequently been developed and applied to various populations of adults with acquired hemiplegia. It has been shown that restraint of the sound side forces use of the affected limb and can promote improved function (Taub et al., 1997) and neural reorganization at the level of the cortex (Liepert et al., 1998). It is not clear whether the constraint itself is the critical factor for improvement or whether it is the specific training of the affected limb which results in improved performance. This has exciting implications for the child with CP, not only for the child with hemiplegia but also for the child with spastic diplegia and asymmetrical quadriplegia. This is an extension of the idea of Bobath, who proposed that forced use of the affected body parts could result in improved activity and function. The case for hemiplegia is clear, but personal clinical experience suggests that forced use of the lower limbs of the child with spastic diplegia while restraining the arms results in improved activity of the lower limbs for postural activity in standing and improved leg movements in walking. Similarly, personal clinical experience with the child who has a significantly asymmetrical spastic quadriplegia shows that forced use of the more affected arm results in improved bilateral hand activities. It is hoped that future investigations will show this to be the case.

PROVIDING OPPORTUNITIES FOR PRACTICE

Therapy should not be confined to the therapy session, nor should a situation exist in which parents are dependent on the therapist. Rather, the therapist should be a facilitator for enabling ideas and modifications to be integrated into all aspects of the child's life at home, school, and all environments encountered during the child's daily routine. This necessitates the training not only of the child but also of parents, carers, and family members in the most useful ways to help the child. This requires both common sense and a setting of realistic, achievable, and relevant goals for each individual person. It will also include the use of equipment and technological aids to enable these goals to be met. For example, special seating and adapted cutlery may enable independence in eating and drinking, or the use of a computer-driven devices may enable greater possibilities for communication and learning, thereby optimizing functional independence.

THE WAY FORWARD

Pediatric therapists might also consider the adult motor control literature, particularly that regarding motor learning. There are three basic factors:

- Active participation
- Opportunities for practice
- Meaningful goals

Research is essential to explore how these components of motor learning, shown to be effective with adults, might be applied to children with CP. Some insight to how these ideas can be applied to children are described in Shepherd (1995).

Although it would seem that there are currently more questions than answers and that there is an

urgent need for evidence on which to base clinical practice, *most* parents and professionals would agree that therapy is beneficial for the child with CP. What is the best therapy approach and how much still remains to be determined and will of necessity be different for each child according to ability and age. However, the current literature suggests that the following are important components of the therapy intervention:

- maintenance of muscle length
- attention to muscle strength,
- acceptance of the limitations of the damaged nervous system while not neglecting the potential for positive adaptation and change,
- a consideration of the need to prepare for adult life,
- a program which aims to achieve meaningful and relevant functional goals, and
- a program which offers a manageable routine compatible with quality of family life.

It may be that drastic changes are not required in what therapists do, but rather a more rational explanation. There is a need for therapists to challenge established ideas, particularly relating to the theoretical basis for the control of movement. Just as important is the establishment of a dialogue and collaboration between clinicians and scientists to ensure that a sound scientific basis is produced to either support or enable the appropriate modification of current practice to ensure the best quality of life possible for every person with CP, regardless of severity.

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