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Evaluation pertinent to the gait of children with myelomeningocele

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Abstract

Many children with spina bifida who require long term and costly clinical management and rehabilitation are seen at the Ontario Crippled Children's Centre (OCCC). The aims of orthopaedic management can best be achieved through an "effective" assessment of each child, which guides the provision of conservative and operative treatment throughout infancy and childhood.

Surgery and orthotic aids are the major ways available to correct or prevent the formation of orthopaedic deformities. At present the only way of assessing an orthosis is to wait and see if it improves function or prevents a deformity.

This paper addresses pilot work undertaken to elucidate the factors which contribute to deformity progression in the lower limbs. The intent was to measure these factors in as cost effective and non-invasive a manner as possible and utilize the information gained in orthotic assessment and development for these children.

The initial goal of the study was to quantify the effect of a prescribed orthosis upon the gait of each child. Some 15 children with a lumbar or sacral level myelomeningocele have been examined in a total of 59 trials. The data collection process involved a three stage protocol implemented by the orthopaedist, physical therapist and engineer. A comprehensive clinical examination, a visual gait assessment from video-tape and an instrumented gait assessment were performed in the OCCC gait laboratory. Assessment criteria were proposed and extracted from the data collected. These criteria were posed after examining the frequency distribution of certain features of gait in the study group. A case study illustrating the application of the assessment is provided.

In examining the performance and influence of an orthosis upon a child's gait situations were identified in which no clear statement of "best" or "better" could be made. The value of the assessment was to point out the trade-offs and *relative* merits of selected orthotic options. By combining the objectivity of data acquired with gait analysis instrumentation with the subjective, but tangible, skills of the experienced observer, significant improvement in performance of the assessment is likely.

Introduction

The Ontario Crippled Children's Centre (OCCC) is a provincial rehabilitation centre for children up to the age of eighteen years. A multidisciplinary team exists at OCCC and the Hospital for Sick Children (HSC) to provide for the clinical management and rehabilitation of the spina bifida affected child. The most severe and frequent form of this disorder is represented by the child with a myelomeningocele which causes extensive problems. The most disabling problem is the effect upon the spinal cord which almost always results in some degree of paralysis to the lower limbs, the bladder and the bowel. The higher the spinal cord is affected the greater will be the total management problem, due to the high probability of associated malformations and secondary complications developing. A comprehensive description of approaches to orthopaedic management has been published (Menelaus, 1980).

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Ambulatory status

A study at OCCC and HSC reported and conducted by DeSouza and Carroll (1976) examined available data to indicate the important factors in predicting the eventual ambulatory status of a child with a myelomeningocele. They found that, for their series, the ambulatory status seemed to depend upon (in order of priority):

(1) The neurological level of lesion.
(2) The motor power present at the neurosegmental level.
(3) The extent and degree of orthopaedic deformities present in the spine and lower limbs.
(4) Age, height and sex of the patient.
(5) Motivation.
(6) Spasticity.
(7) Design and effectiveness of orthoses.
(8) Surgical procedures.

From these determinants it is clear that once a spina bifida child survives the first few months, it is possible to have realistic goals for the child's ambulation abilities; these being largely governed by the 'uncontrollables' of lesion level and motor power. For any child, it is clear that ambulation goals may be strongly governed by the extent and degree of the orthopaedic deformities present.

Orthopaedic management

The aims of orthopaedic management are:

a) To correct deformity, to maintain its correction, to prevent recurrence and to avoid production of other deformities.
b) To obtain the best possible locomotor function.
c) To prevent or minimize the effects of sensory and motor deficiency.

The achievement of these interdependent aims depends upon a correct and adequate assessment at "suitable" intervals, together with conservative and operative treatment as indicated. Surgical and orthotic treatments are complementary in correcting deformities and aiming to prevent others from developing.

Factors in the causation of deformity

The factors responsible for deformity in spina bifida are:

(1) Co-existent congenital malformation.
(2) Unbalanced muscle activity.
(3) Gravitation (external force) effects.
(4) Abnormal bone growth or fractures.

The commonest cause of deformity appears to be unbalanced muscle activity. Deformity is progressive and proceeds more rapidly in infancy and early childhood.

The sequence of affected structures is likely to be;

i. Muscles and tendons
ii. Ligaments and soft tissues
iii. Bone.

Bony deformity develops only months after the initiation of the "deforming force", therefore, the effectiveness of a treatment plan (whether orthotic or surgical) only becomes apparent after an unfortunate delay. Surgical treatment will not be successful in maintaining the correction of a lower limb deformity (if the deforming force still exists) without complementary orthotic fitting.

Orthotics

Having corrected any pre-existing problems by surgery, orthoses are used to prevent deformities from recurring. With an orthosis we can state some realistic goals for its use. (Henderson and Lamoreux, 1969). All an orthosis may achieve is to:

(a) Relieve limb areas which are load sensitive.
(b) Control motion at a joint with respect to range and direction.
(c) Maintain the shape of body tissues in spite of the activity of deformity producing forces.

In addition to these functional goals an orthosis has some acceptance constraints which concern overbracing, cosmesis, cost and effect upon the child's endurance.

With the AFO (ankle-foot orthoses) systems applied to the children in this study several stages are used in their manufacture.

(a) A plaster cast of the limb is made with some correction of foot and ankle position if both possible and necessary.
(b) Rectification and finishing of cast.
(c) Vacuum forming of a thermosetting plastic to the shape of the cast.
(d) Trimming and fitting the AFO to the child and ensuring compatability with shoe type and shoe sole contour.

Aims of the study

The aim was to investigate the nature of an assessment protocol which could enhance the identification of an undesirable orthotic fitting for the ambulatory child. The initial efforts are described here.

The initial goal was to quantify the effect of an orthosis on each child in the study group. This orthosis had been prescribed and fitted by the regular clinic team. After describing the effect of the orthosis provided for each child, criteria were developed to judge the relative value of the observed differences and provide a basis for orthotic improvement.

Subjects

Fifteen children have been examined so far in a total of 59 trials. All the children seen were selected from within the caseload of the Spina Bifida Orthotic Clinic of OCCC and had a low lumbar or sacral level myelomeningocele (9 female, 6 male). All these children were independently mobile with bilateral polypropylene AFO's. The youngest child was 2 years and the eldest 11 years of age (mean 6 years).

Data collection process

The data collection process involved three stages implemented by the team of orthopaedist, physical therapist and engineer:

(1) A comprehensive clinical examination.
(2) A subjective gait assessment from video tape.
(3) An instrumented gait assessment in the laboratory.

The clinical examination

The clinical examination was designed to detect what could be considered as the individual child's locomotor function deficits; including those apparent from an observation of;

(a) Clinical history pertinent to surgery and orthotic aids.
(b) Muscle tone and power in the lower limbs.
(c) Passive ranges of joint motion in the lower limbs.
(d) Spinal alignment and rigidity in frontal and lateral views (sitting and standing).
(e) Standing posture.

In performing this examination the approach was taken that only those features illustrative of a deficit would be noted. This allowed some reduction in the volume of data recorded whilst (hopefully) retaining information of value to the study. As in any "hands on" examination, subjective judgement errors are possible. In this study, group discussion of problems which arose was designed to minimize bias.

Subjective gait assessment

The intent in this section was to utilize the pattern recognition powers of the trained observer. The process allowed the gait of a child (anterior posterior (AP) and lateral (L) video views) to be observed and dissected in a guided fashion. A subjective analysis form, evolved from one used at the Children's Hospital Gait Laboratory in Boston, USA, was utilized (Simon, 1980). The form was scored independently by the orthopaedist or therapist and the engineer. Scoring consisted of indicating on the form the presence of a gait abnormality and the phase of gait in which it occurred.

It should be emphasized here that the aim was not to try and make the gait of these children necessarily normal (which was very likely unrealistic). However, by comparing the assessment forms completed for different orthotic situations, it was hoped to detect the changes in a child's gait which are symptomatic of these introduced orthotic changes. The gait changes observed could then be used to guide the extraction of objective data from the more formal instrumented gait assessment.

Instrumented gait assessment

The gait laboratory at the OCCC has the space and equipment to collect all pertinent data during gait assessment. A PDP 11/34 computer and peripheral equipment provided for the interactive acquisition, manipulation and display of multiple signals.

A 9261A Kistler force platform provides ground reaction force data and was used in conjunction with two orthogonally positioned video cameras. The two camera views were blended on a single monitor and recorded on a time-lapse video tape recorder. This recording could be replayed at varying speed, or field by field. Grey scale copies were made of each field using a Tektronix 4632 hard copy unit. The set of hard copy papers were then digitized using a Tektronix interactive plotter (4662) interfaced to a Tektronix 4051 computer. When digitization is complete the kinematic data may be transmitted to the PDP-11 computer via an RS232 interface for combination with the force platform data. A light beam system was used to calculate average walking velocity along the laboratory. A document describing the gait laboratory instrumentation and configuration is available from the authors.

Methodology

With each subject the clinical examination would be conducted by the therapist and orthopaedist immediately prior to the gait evaluation. As many trials as possible were conducted with the ground reaction forces, 3D video recording and average walking velocity recorded for each trial.

Skin surface reflective-markers were used to define points of anatomical interest. Stick markers were placed at the sacrum and lateral knee joint line. Spot markers were located at the anterior superior illiac spines (ASIS), the greater trochanters, tibial tubercle, proximal to the lateral malleoli and heel and toe. Joint centre positions at the hip, knee and ankle were predicted by relating these known marker positions to physical measurements and prior standing X-rays if these were available. "Normal" data for the prediction of joint centres from surface measurements cannot be realistically used; particularly at the hip. These joint centre predictions were used for the "stick" man representations of Figure 5. The video system was calibrated and ready prior to the child's arrival. The video records were taken and retained both for visual analysis and for correlation with the force platform data.

Total test time was of the order of 20–30 minutes. Force platform data were generated within seconds of a trial in order to verify success or failure. The video records were monitored and reviewed very briefly for each test.

With each child at least two situations, (with or without the prescribed orthosis) were considered and multiple trials conducted for each situation to ensure that comparative data were available.

Discussion of methodology

Speed of testing soon proved to be very important for the successful completion of the study. Many of the children had very short attention spans. It took considerable ingenuity to keep a child amused whilst data were collected and therefore long delays between walking sessions were unacceptable, except if the child appeared to be becoming too tired to continue. Evidence of tiring was detected by monitoring walking velocity and noting verbal complaint. On the basis of experience the use of a fast method of data collection and display would seem essential. For example, it was endeavoured to conduct repeat walking trials within 30 seconds of the previous one.

The child was not told of the existence of the force platform and was instructed to walk toward a toy placed across the walkway and located on a path which would cross the force platform. Initial experiences showed the importance of not indicating the presence of the force platform because this would often lead to a deliberate walking "performance" by these children. Demonstrations of frustration by the research staff, because the child missed contact with the force platform, were undesirable.

Results

Introduction

Having compiled fairly complete data concerning the gait of these children several steps were envisaged;

(a) Compare the gaits of each of these children in the braced and unbraced situations.
(b) Using the observed differences pose some tentative assessment criteria which could best discriminate between braced and unbraced situations.
(c) Apply these assessment criteria to each child to quantify the differences between the braced and unbraced situations and comment on the benefits to the child of these differences.
(d) Make specific orthotic modifications guided by these assessments when possible and repeat the evaluation.

Braced and unbraced gait

The subjective assessment forms were used to illustrate some generalized features of the study group with respect to the effect of the AFO's upon gait. All of the children were capable of unbraced gait for the short period of testing.

The frequency of observation of the chosen gait deviations are shown with respect to their occurrence in a particular phase of gait. Unbraced and braced situations are tabulated in Figures 1 and 2. The numbers in the table represent the percentage of children in the study group who were subjectively judged to demonstrate a particular gait deviation. Figure 3 illustrates the difference between the braced and unbraced situations. The largest negative values indicate the largest reductions in the percentage of children demonstrating a gait deviation. Positive values indicate an increase in the percentage of children demonstrating a particular deviation.

The most significant improvements correlated with the addition of an orthosis are in the control of foot and ankle position and the extent of flexion at the knee and the hip during the whole gait cycle. Very slight generalized improvement is noted with lordosis and anterior/posterior trunk position with the addition of the AFO, although there is a significant increase in the extent of lateral trunk motion.

Additional features in the unbraced situation which are not represented in the figures were considered to be:

FREQUENCY OF OBSERVATION OF GAIT FEATURES
IN THE BRACED SITUATION
(AS PERCENT OF POSSIBLE NUMBER OF AFFECTED LIMBS)

	MOTION	INITIAL CONTACT	WEIGHT ACCEPT.	MID STANCE	WEIGHT RELEASE	EARLY SWING	LATE SWING
TRUNK	Anter/Poster lean	41	41	41	41	41	41
	Right/Left lean	36	45	45	45	45	36
	Rotation	5	5	5	0	0	5
PELVIS	Lordosis	64	64	64	64	64	64
	Trendelenburg	0	0	0	0	0	0
HIP	Flexion	14	14	14	14	14	18
	Abduction	0	0	0	0	9	5
	Adduction	14	23	23	0	0	5
	Inter. Rot.	14	18	23	0	0	9
	Exter. Rot.	9	9	9	23	41	14
KNEE	Flexion	45	45	45	45	45	50
	Hyperextension	0	0	9	0	0	0
	Tibial Progression	0	5	9	0	0	0
	Valgus	0	23	18	0	0	0
	Varus	0	0	0	0	0	0
ANKLE	Dorsi Flexion	0	0	0	0	0	0
	Plantar Flexion	5	0	0	0	0	0
	Eversion	0	0	0	0	0	0
	Inversion	0	0	0	0	9	0
	Inter. Rot.	31	27	27	27	36	31
	Exter. Rot.	18	18	18	41	45	18

Fig. 2. Generalized motion assessment—braced.

FREQUENCY OF OBSERVATION OF GAIT FEATURES
IN THE UNBRACED SITUATION
(AS PERCENT OF POSSIBLE NUMBER OF AFFECTED LIMBS)

	MOTION	INITIAL CONTACT	WEIGHT ACCEPT.	MID STANCE	WEIGHT RELEASE	EARLY SWING	LATE SWING
TRUNK	Anter/Poster lean	45	45	45	45	45	45
	Right/Left lean	27	27	32	27	32	27
	Rotation	0	0	0	0	0	0
PELVIS	Lordosis	68	68	63	68	68	68
	Trendelenburg	0	0	0	0	0	0
HIP	Flexion	45	45	40	23	54	54
	Abduction	0	0	0	9	31	9
	Adduction	32	27	14	0	0	40
	Inter. Rot.	27	27	14	0	0	18
	Exter. Rot.	9	9	9	40	31	14
KNEE	Flexion	64	77	77	77	86	86
	Hyperextension	0	0	0	0	0	0
	Tibial Progression	0	0	32	0	0	0
	Valgus	0	36	32	0	0	0
	Varus	0	0	0	0	0	0
ANKLE	Dorsi Flexion	18	14	14	9	5	5
	Plantar Flexion	41	18	0	9	45	27
	Eversion	36	36	36	36	41	41
	Inversion	0	0	0	0	14	5
	Inter. Rot.	27	27	18	23	18	18
	Exter. Rot.	32	32	32	45	36	36

Fig. 1. Generalized motion assessment—unbraced.

PERCENT DIFFERENCES IN THE FREQUENCY OF
OBSERVATION .... BRACED vs UNBRACED

	MOTION	INITIAL CONTACT	WEIGHT ACCEPT.	MID STANCE	WEIGHT RELEASE	EARLY SWING	LATE SWING
TRUNK	Anter/Poster lean	-4	-4	-4	-4	-4	-4
	Right/Left lean	9	18	13	18	13	9
	Rotation	5	5	5	0	0	5
PELVIS	Lordosis	-4	-4	1	-4	-4	-4
	Trendelenburg	0	0	0	0	0	0
HIP	Flexion	-31	-31	-26	-9	-40	-36
	Abduction	0	0	0	-9	-22	-4
	Adduction	-18	-4	-9	0	0	-35
	Inter. Rot.	-13	-9	-9	0	0	-9
	Exter. Rot.	0	0	0	-17	10	0
KNEE	Flexion	-19	-32	-32	-32	-41	-36
	Hyperextension	0	0	9	0	0	0
	Tibial Progression	0	5	-23	0	0	0
	Valgus	0	-13	-14	0	0	0
	Varus	0	0	0	0	0	0
ANKLE	Dorsi Flexion	-18	-14	-14	-9	-5	-5
	Plantar Flexion	-36	-18	0	-9	-45	-27
	Eversion	-36	-36	-36	-36	-41	-41
	Inversion	0	0	0	0	-5	-5
	Inter. Rot.	4	0	9	4	18	13
	Exter. Rot.	-14	-14	-14	-4	9	-18

-ve values indicate improvement
+ve values indicate deterioration

Fig. 3. Generalized influence of AFO's.

(1) A limited ability to change walking velocity.
(2) The use of a wide base of support during double support phase of gait.
(3) A limited endurance.

Generalized data can only have limited value in guiding treatment for an individual child. This is because many things can contribute to gait abnormalities in the individual child. Menelaus (1980) quotes obesity, defective eyesight, sensory, cerebral and cerebellar factors as being responsible for gait abnormalities, in addition to the more obvious physical difficulties. However, these generalized data allowed the posing of tentative criteria to assess the change in gait of an individual child in response to an orthotic change. In addition, these data allowed a realistic view of the limits of likely success with any orthosis prescribed.

Assessment criteria

The intent was to define an assessment, sensitive to the relative merits of orthotic options for the *individual* child, but with sufficient scope for general application. Because of this, judgment of merit must be made sufficiently broad to suit the wide range of problems of these children.

The generalized features above, led to the following foci for assessments:

(1) Dynamic ranges of motion employed at the hips, knees and ankles (as appropriate) during gait.
(2) External forces and moments (magnitudes and directions) at the hips and knees.
(3) Stance/swing phase temporal ratios.
(4) Subject walking velocity and variability for the trials recorded.
(5) Subject dynamic stability. Judged by a composite factor of width of base of support, ability to change walking velocity and the tendency to unstable modes at the lower limb joints.
(6) Amount of lateral trunk sway.
(7) Endurance.

The emphasis placed on any one of these foci and their criteria will depend upon the individual treatment goals of each individual child. The use of the assessment is best described with a case study.

Case study

C.W. is a male, 6 years of age with a L4 neurosegmental level. He has a developmental and educational level appropriate for his age. He is a community ambulator fitted with bilateral polypropylene AFO's which have a high resistance to flexion and torsion.

In grading passive joint ranges he had no particular problems with good limb alignment. His motor power (graded 0–5) demonstrated hip flexors, adductors, quadriceps at 5; medial hamstrings at 4; hip extensors, abductors, lateral hamstrings, dorsiflexors, plantarflexors, invertors and evertors at grade 0.

Spinal alignment was good with a slight lumbar lordosis in observing him in standing. His AFO's were set at neutral ankle with slight forefoot supination and were paired with rocker bottom shoe modifications. Gait data were collected and the assessment conducted by the team.

The observations of braced and unbraced gait are depicted in Figure 4. The application of AFO's introduced some predictable and observed gait changes.

Considerable improvement during the weight acceptance phase was apparent, with better control of ankle and foot position with reduced hip adduction and internal rotation. The lack of hip abductor power meant that the trunk motion, apparent hip adduction and internal rotation during single support phase, could not be eliminated by the addition of the AFO.

There was an apparent valgus motion at the knee in the weight acceptance and midstance phases of both legs with or without the AFO's.

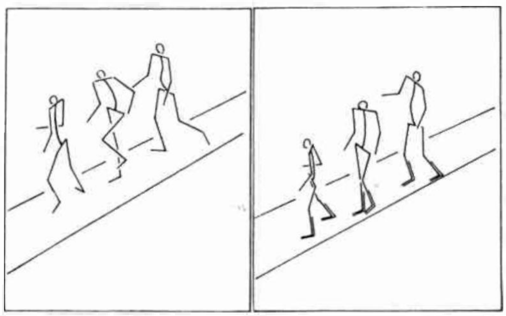

Fig. 4. Case study, influence of prescribed AFO's. Left unbraced, Right braced, showing improved foot and ankle position; reduced hip internal rotation and improved arc of motion at hip and knee.

Objective differences were defined using our assessment criteria. The most striking changes were as follows;

(a) With the addition of AFO's the hip range of useful motion increased by an average of 12 degrees (5 trials).

(b) The knee range of motion remained the same although the arc of that motion changed and there was some 10 degrees less knee flexion at foot contact.

(c) Stability was judged subjectively to increase from '2' to '4' (on a scale 0–5).

(d) The stance/swing ratio for left-right became more even (1·43 to 0·97).

(e) The average walking velocity of choice was significantly increased with the addition of the AFO's.

The stick diagrams shown in Figure 5 illustrate examples of the instantaneous positions of the lower limb segments together with the magnitude and direction of the ground reaction forces. In the interpretation of these diagrams particular attention was given to the peak magnitudes of created moments and to the phases of gait when these moments were transitional from one mode to another; for example, the point of transition from a moment tending to flex the knee to a moment tending to extend it.

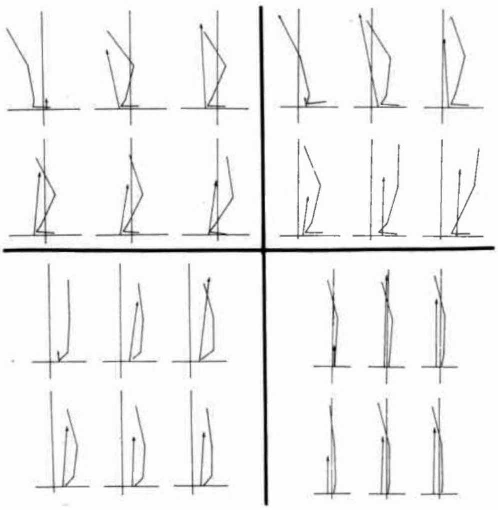

Fig. 5. Case study, top left, a, lateral view unbraced. Bottom left, b, frontal view unbraced. Top right, c, lateral view braced. Bottom right, d, frontal view braced. Seven fields per second.

The first step was to chart the directional tendency at a joint due to the external moments. These were then compared with the likely ability of the child being able to balance these moments with their muscles. Undesirable tendencies could then be identified. For example with C.W., forces attempting to flex the hips would not be greatly resisted by the hip extensors because they were found to be weak upon physical examination.

In the *unbraced situation* (Fig. 5, top and bottom left) the hip moments created by external forces were primarily trying to extend the hip which could be controlled by the hip flexor muscles. Close to midstance the external hip forces produced a low extension moment. Compensatory body movements would always ensure that a flexion moment is never reached as extensor muscle activity cannot be produced to control it. Both limbs were examined but only the right limb is shown in the figures.

In the frontal view the heel, ankle and foot are in poor alignment and are unprotected. The centre of pressure of the ground reaction forces was on the lateral border of the foot and the external forces at the knee were attempting to create a valgus stress at the knee.

In the *braced situation* (Fig. 5, top and botom right) the ground reaction forces are attempting to extend the hip and flex the knee (situations which can be handled by active muscles). In the frontal view the heel, ankle and foot are in good alignment and are protected but the ground reaction forces still act to create a valgus stress at the knee.

In summary, the hip external forces and moments were significantly *higher* but at the knee no significant change was apparent with the addition of the AFO.

Discussion and conclusions

Interpretation of criteria and recognition of undesirable states

The increased magnitudes of the hip external forces and moments may be considered a result of the child's ability to walk faster and with longer strides when fitted with AFO's. The fact that the valgus stress at the knee was not relieved by the AFO was recognized as an undesirable event. Stability was greatly improved with the AFO's. Lateral trunk motion was not significantly changed by the addition of the

AFO's. The value of the assessment in this case was to demonstrate the value and limitations of the prescribed AFO's.

In examining the values of the assessment criteria and comparing braced and unbraced situations it became clear that orthotic fittings often involve compromise. In this case study the addition of the AFO significantly improved the child's mobility and stability on the date of examination. However, the force actions at the knee and hip are still acting in a manner in which progressive deformities are likely. The recognition of these facts leads to the proposal of some orthotic modifications. It is wished to reduce the undesirable forces without sacrificing stability, mobility and endurance to any great degree. In practical situations it is also necessary to consider the additional constraints of cost and patient or parent acceptability. The strategy applied by the orthotist in this case was to change the shoe sole contour to bring the ground reaction forces medially during stance phase and thereby reduce the valgus stress at the knee. The stability and more obvious gait improvements need not be sacrificed in an attempt to reduce the likelihood of deformity development.

In further developing this assessment to consider higher levels of spinal lesion it is clear that the emphasis placed on assessment of endurance and stability will increase. The work of Stallard and Rose et al. (1978) is interesting in this regard and is being studied with a view to incorporating their methodologies, when appropriate, into the assessment.

Conclusion

In conclusion it should be emphasized that in many cases operational constraints make the implementation of an orthotic specification difficult or impossible using routine fabrication methods. For this reason the assessment system described cannot be instantly transplanted into the routine clinical process. It is expected however, that it can provide clear guidelines for orthotic research and development as well as making us better aware of how to present gait information to the clinical decision-maker. The best course of action for an individual child can then be chosen with cognizance of what can be realistic in terms of his or her ambulation.

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