Cerebral palsy and rhizotomy

A 3-year follow-up evaluation with gait analysis

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A recent increase in the popularity of selective posterior rhizotomy for reduction of spasticity in cerebral palsy has led to a demand for more objective studies of outcome and long-term follow-up results. The authors present the results of gait analysis on 14 children with spastic cerebral palsy, who underwent selective posterior rhizotomy in 1985. Sagittal plane gait patterns were studied before surgery and at 1 and 3 years after surgery using a digital camera system. The parameters measured included the range of motion at the knee and thigh, stride length, speed of walking, and cadence. The range of motion at the knee was significantly increased at 1 year after surgery and further improved to a nearly normal range at 3 years after surgery. In contrast, postoperative measurements of thigh range exceeded normal values at 1 year, but decreased toward normal range at 3 years. While improvements in range of motion continued between Years 1 and 3, the children developed a more extended thigh and knee position, which indicated a more upright walking posture. Stride length and speed of walking also improved, while cadence remained essentially unchanged. This 3-year follow-up study, the first to examine rhizotomy using an objective approach, has provided some encouraging results regarding early functional outcome.

KEY WORDS • gait • dorsal root • rhizotomy • cerebral palsy

Spasticity is a major problem in children with cerebral palsy. Cerebral palsy is a motor disorder due to a nonprogressive perinatal insult to the developing brain. Approximately 25,000 children are born with or develop cerebral palsy in the United States each year. One of the neurosurgical options available for reduction of spasticity in cerebral palsy is selective posterior rhizotomy. Posterior rhizotomy for relief of spasticity was first reported in 1908 by the German neurosurgeon Foerster, although he credited Monro with similar work as early as 1904. In 1913, Foerster reported a series of 159 patients in whom he completely divided the posterior roots from L-2 to S-2 bilaterally, but spared the L-4 roots. Although Foerster's clinical results seemed encouraging, the procedure was almost overlooked by the neurosurgical community during the next half-century. It was not until Gros, et al., revised the surgical technique and divided only a portion of the sensory nerve rootlets comprising each posterior root to reduce sensory loss that the approach became more acceptable. In 1978, Fasano, et al., described the use of electromyography (EMG) during electrical stimulation of the posterior nerve rootlets in spastic patients as the basis for selective rootlet division, and this approach was adopted by others. Peacock, et al., further modified Fasano's approach by changing the operative site from the level of the conus to the cauda equina in order to ensure preservation of the lower sacral nerve roots involved in bowel and bladder control.

Within the past 4 years, there has been a major resurgence of interest in the procedure and there are now over 30 centers in North America offering this surgery. With the increase in patient numbers and the apparent endorsement of the procedure by some in the neurosurgical community, objective analysis of the long-term results becomes essential.

Foerster and Fasano and Broggi provided subjective and anecdotal evidence of improvements in function following posterior rhizotomy, the latter with a 15-year follow-up period in 80 patients. Peacock, et al., found reduction in spasticity and improvement in function in 60 patients after selective posterior rhizotomy; follow-up evaluation up to 7 years revealed maintenance of...
Gait before and 3 years after rhizotomy

In order to obtain more specific and objective data, we began routine measurement of walking and crawling patterns of patients before and after selective posterior rhizotomy. The results of approximately 1 year after surgery were reported by Vaughan, et al., for 14 ambulatory patients and revealed a significant increase in thigh range, knee range, and stride length. The cadence was virtually unchanged and, although the speed of walking increased, the difference was not statistically significant. It was concluded that rhizotomy reduced spasticity, thus allowing an increase in functional range of motion during gait which contributed to a longer stride length. These results confirmed our clinical impressions of gait improvement in spastic children following the rhizotomy procedure. However, the follow-up period was not adequate for evaluation of long-term effects. The purpose of the present study is to provide an objective assessment of the gait patterns of patients undergoing selective posterior rhizotomy after a postsurgical period of 3 years, and to compare these results with those obtained after 1 year.

Clinical Material and Methods

Patient Selection

The goal of the examination and selection process was to identify those patients who were mainly handicapped by spasticity and not the other features of cerebral palsy. Thus, clinical examination of muscle tone, reflexes, strength, range of motion, balance, and motor control was performed. Individuals with cerebral palsy who had spasticity but lacked rigidity, dystonia, athetosis, and ataxia were chosen. Because improvement in walking was our goal for this group of patients, it was important to ensure that they had adequate trunk control, balance, and antigravity strength, and did not have severe fixed contractures. Children with truncal hypotonia, weakness, or tendons overlengthened by previous orthopedic surgery were not considered for the procedure. Children of normal intelligence with bilateral lower-extremity spasticity and minimal upper-extremity involvement (spastic diplegia), good trunk control (ability to side sit), lower-extremity strength, and the ability to walk were considered the best candidates for the study.

Twenty-nine spastic children with cerebral palsy underwent selective posterior rhizotomy in 1985. Fourteen were able to walk prior to surgery and thus could be studied using gait analysis preoperatively and again 5 to 14 months following rhizotomy (mean 9 months). At the time of surgery, the age range was 2 to 14 years (mean 8 years). Eleven of the original 14 patients were available for reassessment in 1988 at a mean postsurgical period of 36 months. All patients received preoperative and postoperative physical therapy. For purposes of comparison, gait data were also collected for nine normal children with a mean age of 5 years.

Operative Technique

The procedure was performed under endotracheal general anesthesia without the use of long-acting depolarizing agents. The patient was positioned prone with bolsters under the chest and pelvis to allow the abdominal wall to move freely and to prevent epidural vein distention. Access to the lower extremities for intraoperative EMG and visual monitoring was ensured by careful positioning and draping of the patient. Accurate identification of the lumbosacral posterior roots and rootlets is difficult at the level of the conus, which is accessed using a T12-L1 laminectomy. We therefore exposed the cauda equina through laminectomies from L-2 to L-5 with careful preservation of the posterior facet joints. The posterior roots and their levels were identified by visual anatomical features with accuracy confirmed using electrical stimulation. The S-1 root was usually the largest, and stimulation of its anterior root produced flexion of the knee and ankle plantar flexion. The S-2 root was significantly smaller, and ankle plantar flexion and toe flexion occurred on stimulation of its anterior root. The plane separating the posterior and anterior roots was clearly visualized. The posterior root was broader, flatter, and lighter in color than the anterior root. The electrical threshold for a motor response was much lower for the anterior root than the posterior root. By counting upward from the confirmed S-1 root, the L-2 root could be easily identified at its dural exit point. The posterior root of L-2 was separated from the anterior root, and the two to four rootlets comprising the posterior root were stimulated in turn by means of two insulated microneurosurgical hook electrodes.* The threshold for a motor response was identified using a 0.1-msec square wave stimulus. A tetanic stimulus was then applied to the rootlet at 50 Hz (nonsinusoidal) for 1 second. The responses were monitored using EMG needle or surface electrodes.

For the patients in this study, two muscle groups were sampled simultaneously. For identification of the L2-4 rootlets electrical activity from the quadriceps and adductor muscles was sampled, and for the L5-S2 rootlets the gastrocnemius and tibialis anterior muscles were monitored. Rootlets were sectioned if they were associated with a low threshold for motor response, a sustained response beyond the 1-second stimulus interval, or spread to inappropriate muscle groups. The recording technique has been refined since these patients were treated, resulting in better selectivity and a decrease in the average number of rootlets divided. We now monitor EMG patterns from 10 muscles simultaneously using the chart recorder of an electroencephalograph.† Responses are recorded from the hip ad-

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* Microneurosurgical hook electrodes manufactured by Aesculap Surgical Instruments, Burlingame, California.
† Electroencephalograph manufactured by Nihon Kohden Inc., Irvine, California.
FIG. 1. Various electromyographic responses recorded during intraoperative electrical stimulation of the posterior rootlets using a 10-channel recording system. A: Decremental responses which are considered to be normal. B: An abnormally sustained response in the left quadriceps. C: Multiphasic clonic patterns seen in reaction to a steady stimulus. The rootlets associated with these responses are divided. D: Abnormal spread to ipsilateral hamstrings and contralateral tibialis anterior and hamstring muscles following stimulation of a left L-2 rootlet with an incremental pattern in the left hamstrings.
Gait before and 3 years after rhizotomy

The gait cycle may be divided into specific events. For a normal subject, shown here, the stance phase (from foot contact to foot off) constitutes 60% of the cycle, while the swing phase represents 40%. All events are referenced to the right side.

Rootlets associated with decremental or squared-type responses are spared. Those associated with incremental, clonic, or multiphasic patterns are divided as well as those associated with sustained contractions or with spread to inappropriate muscle groups (Fig. 1). The decision regarding division of nerve rootlets is also based on the preoperative clinical assessment, the number of rootlets previously divided, and the relative degree of abnormality. For severely spastic children, where many rootlets are associated with an abnormal response, care is required to avoid excessive deafferentation. After bilateral stimulation involving 50 to 60 rootlets, approximately 25% to 50% of rootlets are sectioned.

Gait Analysis Procedures

The kinematic analysis system consisted of three components: lightweight retro-reflective markers, a digital camera, and a personal microcomputer. The system was portable, enabling evaluation of patients in distant geographic areas. The markers were placed at the hip (greater trochanter of the femur), knee (lateral femoral epicondyle), and ankle (lateral malleolus) of each child. Two-dimensional sagittal plane displacement data were collected during gait for both the left and right lower limbs. Within minutes of completing the walking trial, the x and y coordinates of each joint (as a function of time) were displayed on the computer monitor and a variety of parameters were derived. These included cadence (the number of steps taken per minute), stride length (the distance in meters from foot contact to the subsequent ipsilateral foot contact), and average speed, which was calculated as follows: average speed (m/sec) = cadence (strides/sec) x stride length (m), where there are two steps per stride. The gait cycle, with relevant temporal events, is illustrated in Fig. 2.

The knee and thigh angles were also derived from the displacement data. The angle at the knee joint was defined as the angle between the thigh and calf (Fig. 3 upper). The thigh angle was defined as the angle between the thigh and the vertical axis (Fig. 3 lower). Other parameters derived from these angles were: the knee range (maximum knee extension to maximum knee flexion), the knee mid-range point (the point halfway between these extremes), the thigh range (maxi-
The knee angle plotted as a function of the thigh angle for a normal adult, showing the range of motion and mid-range point parameters. The curve progresses in clockwise fashion with foot contact (FC) and foot off (FO). At FC the knee is fully extended while the thigh is maximally flexed to about 20°. During the stance phase the thigh extends to about −20° and then flexes again after FO. The knee flexes slightly after FC and then extends during stance until just before FO. At the beginning of the swing phase, the knee flexes to about 60° and gradually extends to 0° in anticipation of FC.

The mean values for the right and left sides were determined for all of the gait variables and used for statistical analysis.

Results

For ease of understanding, the cadence, stride length, and average speed will be expressed in order as follows: pre-surgery/1 year postsurgery/3 years postsurgery/normal. Data for nine normal children have been included for the purpose of comparison. The mean results for cadence were 109/105/103/115 steps per minute. The mean stride lengths were 0.72/0.87/1.03/0.90 m, and the average speeds were 0.67/0.79/0.90/0.85 m/sec. For the patients, cadence decreased slightly during the 3 years following surgery, although the differences were not statistically significant. Stride length was significantly improved after 1 year and at 3 years increased by almost 50% from 0.72 to 1.03 m. Average speed of walking was significantly increased only after the 3-year period.

The ranges of movement at the knee and thigh were substantially increased after rhizotomy. The thigh range was slightly less than normal preoperatively and exceeded normal at both the 1- and 3-year follow-up examinations, although there was a slight decrease toward normal at the 3-year study. The range of knee movement was considerably limited prior to surgery, significantly increased after 1 year, and increased to nearly normal by 3 years after surgery. The mid-range point in knee movement was significantly increased after 1 year, indicating an excessively flexed knee position, but returned to a more normal value after 3 years. The mid-range point for the thigh did not differ significantly from the preoperative value over the study period, although it tended to be increased at the 1-year point.

Discussion

Complications

Postoperatively, none of the patients developed wound complications or problems with bowel and bladder sphincter control. In no patient could any sensory deficit be detected in the dermatomes innervated by the lumbar-sacral plexus; increased sensitivity to light touch was noted in all patients after surgery but resolved spontaneously within 5 to 10 days. Although the follow-up period is relatively short, there has been no clinical or radiological evidence of spinal instability or deformity as a result of the multiple-level lumbar laminectomies, probably because of careful preservation of the posterior facet joints.

Spasticity and Range of Motion

The primary result of selective posterior rhizotomy is the reduction of spasticity. This is reflected by im-
Gait before and 3 years after rhizotomy

Improvement in the range of motion at the knee and thigh during gait which was maintained throughout the study period. The thigh range was initially close to normal and exceeded normal values following surgery. The knee range was quite limited preoperatively and then approached the normal range by the 3rd postoperative year. This is believed to be due to reduction in spasticity in muscles acting across two joints such as the hamstrings and rectus femoris muscles and possibly to reduction in co-contraction of muscle groups across the hip and knee joints. This improvement in thigh and knee range has allowed patients to increase their stride length and speed of walking.

Significance of Mid-Range Points

Whereas the range of motion data are probably a measure of reduction in spasticity, the mid-range points provide insight into the degree of strength and control a patient exhibits during gait. The minimum, maximum, and mid-range points of the thigh and knee for normal gait occur at specific points during the normal gait cycle (Figs. 2 and 3). These angles differ in the spastic child due to muscular co-contraction, restrictions in range of movement, and other features of cerebral palsy such as synergistic movement patterns, weakness, and lack of motor control (Fig. 6). The increased value of the knee mid-range point after the first postoperative year was indicative of a more flexed standing posture in comparison with preoperative and normal studies. A flexed knee posture is often caused by weakness or lack of control of the calf musculature. The improvement in knee posture indicated by a lower knee mid-range value at 3 years suggests development of better strength and control.

Stride Length, Cadence, and Speed

Improvements in range of motion appeared to be a major factor producing increased stride length found at both the 1- and 3-year follow-up periods. Although limb growth with maturation may contribute to changes in stride length, the dramatic changes with simultaneous increases in range of motion noted in our patients make it unlikely that this was a function of growth alone. Cadence remained relatively stable over the 3 years, but had a decreasing trend in accordance with the findings of Sutherland, who identified a decrease in cadence with normal maturation. The increased stride length without a significant change in cadence allowed patients to improve their average speed of walking. Speed is difficult to control, however, and can be influenced by mood or motivation. The standard deviation for speed among the normal children tested was as much as 0.20 m/sec. An increase in average speed for the patients is an important reflection of functional improvement, although the changes in range of motion are probably more direct representations of the benefits of the procedure.

Conclusions

Although posterior rhizotomy has been used as a surgical approach to reduce spasticity for over eight decades, this study is the first to examine functional outcome of an objective basis. This 3-year follow-up study, using a simple sagittal-plane gait analysis system, has provided interesting data regarding early postoperative outcome and development of changes over time. The patients undergoing selective posterior rhizotomy in this series had significant increases in knee and thigh ranges of motion with thigh range exceeding normal values and knee range approaching the norm. The mid-range points, indicative of control, initially reflected a more flexed standing posture which later improved. This suggests that patients can increase their strength and muscular control following selective posterior rhizotomy, and that physical therapy may make an important contribution to their functional improvement. Future prospective studies should concentrate on three-dimensional motion analysis of gait, measurement of energy cost, and the integration of motion, force, and EMG data. In time, long-term studies will provide clinicians with important evidence of the functional benefits that rhizotomy can offer the spastic patient.

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