A Simple Treatment of Genu Recurvatum in Ataxic and Athetoid Cerebral Palsy

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ABSTRACT: An inexpensive, simple treatment for ataxic- or athetoid-related genu recurvatum is presented with analysis of the relevant gait mechanics. An exaggerated posterior heel flare is used in combination with a functionally dorsiflexed, below-knee orthosis to overcome terminal swing phase recurvatum at heel strike, and to provide an effective forward knee thrust through the solid ankle link. This combination is very effective in some patients, even when more extensive treatments have failed. It is easily reversible. Computerized gait analysis, used in this report for illustration, is not essential for implementation, nor for patient selection. However, video examinations are useful for adjustment of the treatment geometry.

Introduction

Genu recurvatum in cerebral palsy has been effectively treated with below-knee orthoses (BKOs)\(^1\) when it is caused by slowed forward knee travel secondary to impaired ankle dorsiflexion. Causes located above the knee, such as inappropriate quadriceps activity, have not been successfully treated by this method. Recurvatum associated with ataxic or athetoid cerebral palsy is included in this group, and is most difficult to overcome without introducing other functional problems. A treatment for some of these patients, which is inexpensive, noninvasive, and without complication, is the subject of this article.

A distinguishing characteristic of the patient group most suited to this treatment is recurvatum of the swinging knee, which occurs just prior to heel strike. An alarming backward deformation of the knee occurs as floor contact is made.

Materials and Methods

The author has used an exaggerated posterior heel flare affixed to the shoe in combination with below-knee orthoses in mild, "functional dorsiflexion." Functional dorsiflexion is a measure of the angle between the sole of the shoe and the tibia when the ankle region is rendered rigid by fusion, cast, prosthesis, or braces. Neutral functional dorsiflexion would have the tibia pitched approximately 7° to 10° forward with the shoe flat to the floor.\(^2\) This treatment has been successful in cases where conventional methods have failed.

Shoes were provided with heels which protruded posteriorly by about one inch. These heels usually had an additional extension up the back side of the shoe for strength. Some were simply made by exchanging adult shoe heels for pediatric shoes heels, allowing backward protrusion.

In combination with the BKO, the shoe provided any needed heel height for functional dorsiflexion (leading edge of patella pitched forward to be aligned vertically over the metatarsal head-neck junction).

Results

Ten patients with cerebral palsy, who were free of ankle, knee, and hip joint contracture or restriction due to spasticity, were treated with the procedure described.

One 10-year-old ataxic girl, who had a slow but steadily moving gait, was treated occasionally by the author, but primarily at another institution. BKO and heel flare were initiated on one side. The recurvatum was overcome without loss or gain in function. Posterior knee surgery was elected following a computerized gait analysis at the other institution. One year postoperatively the patient demonstrated a crouch gait with 45° of flexion at the hips and knees. There were prolonged static pauses between steps. Stance was wider, and less support was required for balance than before, but cadence was much slower.

Three athetoid patients were intolerant of the method. The positive knee effects were offset by deterioration of function. Increased hesitancy and difficulty initiating steps were noted with or without the flare as long as the BKO was worn.

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The remaining six cases, ages 7 to 12, have been treated successfully for an average of 3 years. There were no complications in these cases. Individual problems, however, have required individual modifications.

In two cases the BKO was converted by cutting back the forefoot portion of the orthosis to a heel cup that extended up the leg with only a very short plantar surface ("snub-nose BKO"). This provided improved tolerance of treatment without loss of control. Two patients had the shoe heels extended medially and laterally for enhanced medial-lateral stability. This improved walking but interfered somewhat with adaptive gym activities which required side stepping. One patient, who was significantly improved in walking, found it impossible to get up from the floor unassisted, the cause being loss of extreme dorsiflexion which is needed to perform this activity.

**Case Study**

A highly intelligent 14-year-old boy with ataxic cerebral palsy has been followed for 2 years with before and after gait analysis. His gait demonstrated progressively severe and uncomfortable recurvatum. An apparent hesitation of the body occurred after heel contact as the knee rapidly hyperextended. Sixty degrees of recurvatum was clinically measured bilaterally. Video analysis found varying degrees of recurvatum in gait from cycle to cycle, measuring about 40° on the left and 30° to 35° on the right. Six different kinds of orthotic treatments had been attempted previously. Each had utilized, in one form or another, direct restriction of knee hyperextension. Fixation of ankle movement was provided by two braces. Average brace cost was approximately $800. The patient eventually refused to wear the braces because he was disabled by them. BKOs with anatomic dorsiflexion did not restrict or improve his gait. Heel contact, following swing phase, was not followed by foot flat until terminal stance. Occasionally there was no toe contact with the floor.

A posterior heel extension was added to each shoe to be worn in combination with the BKOs. Recurvatum in late swing, just prior to heel strike, was still present; it arrested at heel strike and reversed into knee flexion as foot flat occurred. Using insert heel lifts during a trial period of several weeks optimized the amount of functional dorsiflexion required for fluid gait. Later, heel modifications incorporated this angle. Knee hyperextension, tested manually, steadily decreased over the 2-year period of this treatment. During this time no other treatment was used. Presently, clinical examination discloses a maximum recurvatum of 20° on the left and 10° on the right.

**Materials and Methods**

Non-orthogonal, biplane video motion analysis, with a sampling rate of 60 fields per second, was employed. Reflective tape markers on the skin provided targets for computer-assisted video digitization. An anterior pelvic stick was used to define a reference pelvic plane. Hip loci and pelvic center were computed from an embedded pelvic coordinate grid.

Telemetry surface EMG\(^4\) was represented in the video image as envelope activity in bar graph form. The rejected braces were worn for video examination on one occasion.

**Results**

**Knee Braces**

The multiple (knee constraining) failed braces caused pain as the patient's knee pressed against the point of restriction. The result was the knee being as extended as the brace would permit without utilization of the potential free flexion range of the brace, producing bilateral vaulting. The gait was essentially that of a patient in bilateral long leg casts aggravated by the ataxia. It was very difficult to obtain an interpretable unassisted gait cycle.

**No Treatment**

Unbraced walking was effective (Fig. 1), although it appeared awkward due to ataxic arm, body, and leg movements. Stride length was 83 cm (normal for stature is 100 cm to 120 cm) taking 0.93 seconds (normal cadence, 63 stride/minute). Double limb stance was 32% (normal for age, 18% to 23%). Pelvic vaulting was minimal indicating (with other factors considered) that the knee mechanism, although abnormal, was effective as a determinant of gait.\(^5,6\)

Some recurvatum preceded heel strike and then was followed by more rapid and severe recurvatum. Peak recurvatum on the left was generally 40° to 45°. The right knee generally exhibited 5° to 10° less recurvatum than the left.

**BKOs**

BK0 treatment was ineffective when used alone and increased overall body sway. Heel strike often was not followed by toe strike. Heel strike was followed by a rapid backward knee thrust more violent than untreated, but of similar magnitude. This backward knee thrust coupled with BK0 ankle rigidity caused the toe to raise further from the floor just after heel strike.

**BKOs and Posterior Heel Flairs**

The combination of BKOs and a posteriorly extended heel (Fig. 2) produced a stride length of 100 cm taking 1.2 seconds (cadence of 50 strides/minute). Double limb stance was 17%. Pelvic vaulting was minimal, indicating that the provided knee flexion was effective in degree and timing as a determinant of gait. Long-term, the device reduced, but did not totally prevent the recurvatum that usually occurred just before heel strike. It did not prevent slight recurvatum from occurring at terminal stance phase.
in the left knee. The latter could be reduced by more functional dorsiflexion (using a higher heel lift) but this could result in too extreme a forward thrust of the knee after heel strike which compromised fluid gait.

EMG

There was tremendous inconsistency in the gait EMG activity. Hamstring activity, normally apparent at terminal swing phase, was often absent. Quadriceps activity often preceded the recurvatum seen just prior to heel strike, but did not necessarily continue through the full phase of recurvatum. The recurvatum was initiated by inappropriate muscular firing, but was carried to its fullest extent passively by the mechanical factors inherent in weight acceptance in early stance phase.

Heel Rise

Terminal stance recurvatum did not require quadriceps overactivity. By voluntarily decreasing the stride length, terminal stance recurvatum was reduced. Normally, after foot flat and after midstance, a rise of the heel, with pivoting on the toe, carries the stance knee forward. This was deficient, and in combination with a robust stride, the knee was subsequently left behind. There was a tradeoff between increased functional dorsiflexion needed to reduce this, and exaggerated foot slap associated with excessive functional dorsiflexion.

Discussion

Normally at heel strike, knee flexion occurs and shortens the imaginary line connecting the hip and ankle of the stance limb. The shortening of this line occurs as it approaches a vertical position\textsuperscript{2,5,6} (the author's definition of midstance). It lengthens as it passes vertically due to the knee extension which normally follows midstance. Additional, functional limb length past midstance is provided by heel rise on the forward pivot of the forefoot. As a result, a more level path of travel of the ipsilateral hip occurs during stance phase. The inertia of the body resists an abrupt upward thrust of the hip and demands some sort of shortening of the carrying limb (hip to ankle line) as midstance is approached.

Although pathologic and destructive of human anatomy, increased abrupt recurvatum at heel strike provides an alternate mechanism of gait. The mere elimination of progressive recurvatum without provision of progressive knee flexion at heel strike, as often accompanies the use of standard knee-ankle-foot orthoses, converts a poor walker to a nonwalker. Because stance phase only requires about 20° of knee flexion to be normal, it is possible that 20° of recurvatum also can be utilized as a determinant of gait.

The use of a dorsiflexed BKO, that is, a solid ankle device with dorsiflexion, fails because heel contact may not be followed by flat foot in these patients. They will walk on their heels and perhaps not make toe contact until terminal stance. A posterior heel flare produces a more posterior point of heel contact and a longer lever arm for a plantar flexion moment. Linked through a solid ankle system, an effective forward knee thrust at heel strike results. The functional dorsiflexion of the shoe-BKO com-
The combination becomes effective once foot flat is assured (Fig. 3).

In addition to an alteration of a “line of force” relative to the point of floor contact, there is a dynamic downward and forward force applied to the knee at heel strike. The forward vector is high initially whereas the downward thrust rises from a low value at contact to a peak value after contact. In addition, there is the forward inertia of the limb segments and the normal or abnormal actions of muscular contraction against the point of resistance, all contributing to torques either favoring forward knee motion or backward knee motion. These are about the ankle joint if the ankle is free, or about the heel contact point if the ankle is solid. The available pathway to forward knee motion about the pivot point is significant in that rotary motion can be upward and against gravity and against the inertia of the body above, or not. The posterior heel flap elongates the lever arm which multiplies the forward vector. It decreases the horizontal lever arm which is a multiplier of the downward-backward vector. The slope of the path of possible knee travel is also altered in that it is less steep, of lower amplitude, and hits peak height more quickly via a shorter arc.

Excluding the contributions of gravity and muscle action, approximate net torques were calculated for each of the three configurations: free ankle, BKO, and BK with flap heel, using unit length from the tracings (eight units to the tibial segment) and an arbitrary initial vector. The free configuration had a net torque factor of ten to overcome abnormal factors. The BKO increased this to 37 and the flap further increased it to 54 units. If the knee cannot travel upward, it can, and sometimes does, travel sideways and then forward. The latter is occasionally seen on video and is very difficult to quantitate.

A hesitation at the knee can decelerate the hip and produce a lurch (body traveling forward as the hip slows). We have seen where the center of gravity of the body continues smoothly ahead while the stance side of the body, which is decelerated, stays behind. This latter phenomenon is assumed to be an ataxic movement; it is actually a secondary rotatory abnormality with which the patient must contend. The ceiling view reconstructions of pelvic motion show this phenomenon.

The contribution to vaulting of the decelerated knee is also demonstrated (Fig. 2, pelvic displacement). There is more pelvic rise over the left stance leg which has the residual problem. Many athetoids will not tolerate solid ankle braces in any configuration. They have developed a series of movements at the ankle on which they depend to offset athetoid movements above. Foot contact with the floor may be essential to remain ambulatory. In cases where the tolerance of BKs is marginal and other choices are few, the foot piece of the BKO may be cut back...
allowing more foot exposure and freedom in foot control. Hopefully, a point can be reached where the BKO is tolerated and the effects on recurvatum are not lost.

Overall, EMG patterns have not been consistent between patients. Experience has shown that muscle transfers based on EMG findings in this patient population are notoriously unpredictable.

A trend toward an absence of hamstring activity at terminal swing phase associated with a brief burst of activity of the quadriceps group prior to heel strike has been observed. In the illustrative case, hamstring activity seemed to improve as the deformity decreased and treatment progressed.

It appears that the major portion of the recurvatum is mechanical reaction and not prolonged muscle activity. Inappropriate terminal swing phase muscle action produces a small initial degree of recurvatum which encourages a larger reactive recurvatum under the forces of weight acceptance, body inertia, and the subsequent need for the leg to shorten (hip to ankle distance) as the body comes forward. In these abnormal circumstances the path of least resistance is recurvatum. The patient learns this and then actively contributes to it as a more effective means of walking in comparison to stiff legged vaulting.

Fig. 3: Geometry at heel strike from a recurvatum patient was used to compare the mechanics of three circumstances: free ankle, BKO and normal shoe, and BKO and heel flair shoe. A convenient unit of measure was used which divided tibial length into eight parts. The leg is shown below and the vector components (F, forward; D, downward) are illustrated operating through the relevant vertical (v) and horizontal (h) lever arms. The forward and downward force vectors compare the leverage contribution of the respective geometries. The free ankle configuration on the left shows an arbitrary net forward torque of 10 units. The radius about the free ankle joint extends to the knee. The BKO and shoe combination (middle figure) moves the fulcrum distally and posteriorly to the heel (ankle is rigid); a measure of 37 units results. The radius of this mobile link is from heel tip to knee.

The addition of a posterior heel flair has several subtle effects. The radius of torque leverage is increased and the center of motion (heel tip) is displaced posteriorly. The arc to attain level motion (zero slope) of the knee is shortened. A torque value of 54 units is calculated. The forward rolling forces, acting at the knee, must overcome backward knee thrusts from abnormal muscle action, increased downward thrust that develops as the body moves forward while the knee is still behind the fulcrum, and resistance to upward knee movement produced by the lever arm of the applied force (at the knee) to the arc of radius about the fulcrum (ankle if free and heel if solid). Notice the required rise of the knee for each configuration. The latter is the most unsatisfactory on the left (free ankle), better with the BKO (middle), and best on the right (BKO and posterior flair). A posterior flair without a solid ankle couple would be ineffective, producing a foot slap after heel strike rather than a forward thrust on the tibia.

The small sketch of a shoe on the right shows the typical appearance of a posterior heel flair as described above. The flaired heel may incorporate a lift as necessary to increase functional dorsiflexion. The average cost is about $5.

References