# Brace-to-Body Dynamics

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For over twenty years the results of the studies done on human locomotion at the Biomechanics Laboratory, University of California at Berkeley, have been available to the orthotics profession. Perhaps the fact that these studies were oriented toward prosthetics is the explanation as to why their findings have not been applied more aggressively to orthotic problems. Traditionally, orthotics and prosthetics have been practiced as separate professions, and although the two have become more closely associated in recent years, it appears that orthotics may still be in the grip of past traditions.

While there is no question that intensive orthotic research is the ultimate to sound future progress, it is questionable as to whether orthotics is making as imaginative a use of current biomechanical information as it might in the present. What follows is a suggested method of analyzing the interactions which take place between a brace and the human body, i.e., the effects which a mechanical system (a brace) has upon a biomechanical system (the human body) and vice versa. For the lack of a better term these interactions will be referred to as—**brace-to-body dynamics.** The proposed method permits control of brace-to-body dynamics, by 'programming' the control of motion. 'Programmed' motion control being here defined as 'planned' or 'allowed' motion within a given brace system versus static control of every movable segment that a brace system may encompass.

With the armamentarium presently available to the orthotist, much can be done in several areas to improve brace-to-body dynamics, and in so doing improve the patient's functional performance. The adult patient can be braced more satisfactorily than a child, as the

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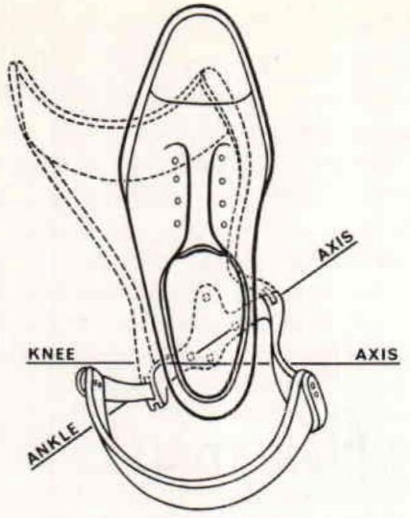


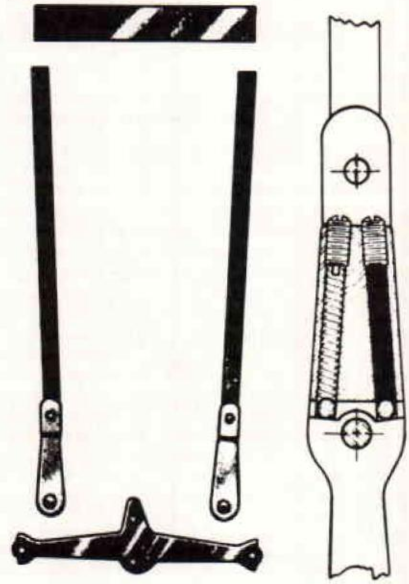

Fig. 1A
BK brace for an adult with accommodation for external tibial torsion and anatomical alignment of the foot to the knee and ankle axes. Brace with posterior calf band is illustrated to give a clearer view.

maximum degree of his external tibial torsion is fixed; therefore some accommodation can be built into the brace (Figure 1). However, a brace is not presently available which can provide necessary motion controls, and yet accommodate the normal development of external tibial torsion in the child who must wear a brace during his growing years.

Two examples of the 'programmed' brace-to-body dynamics analysis technique are presented to demonstrate its functional application. The rationale for the designs is based on two primary premises: 1.) The complex sequence of motions which enable man to walk in an upright position are dictated by the laws of motion. Man's obedience is not an act of will—however, his locomotor system must practice absolute obedience. 2.) A brace has but one function—that is, to control body motion. Its design is therefore subject to the same laws of motion as the body it serves.

The following is a design of a BK brace for a hemiplegia patient with the common pathological condition of a varus foot due to a spastic tibialis anterior (the only dorsiflexor functioning). The patient's plantar flexors are not spastic. The knee is unstable due to weak quadriceps.

Each component of the design is listed, followed by the rationale for its use.



DOUBLE UPRIGHT BK BRACE
Spring Dorsiflexion and / or Plantar Flexion
(Note replacement of one spring with solid rod.)
FIG. 2

1. Bilateral Pope double spring-action ankle joints and uprights. The anterior springs are to be replaced with steel rods, thereby converting the joints to rigid (slightly less than 90°) anterior stops. The posterior portion should permit 15° of plantar flexion against the spring's resistance. (Figure 2.)

RATIONALE:

The anterior stops check the forward progress of the tibia in the sagittal plane as it rotates over the foot. Its forward rotation is checked at 2° to 3° forward of a 90″ relationship to the fixed foot. This setting will maintain the knee in its normal, slightly fixed position during mid-stance. This setting also prevents any tendency for the anterior metal band (see #2) to cause genu recurvatum. The posterior setting of the ankle joints permits the normal range of plantar flexion to occur between heel-strike and foot-flat. The springs resist the force of gravity as well as the resultant force from the floor, thereby mechanically producing the function normally required of the pretibial muscles. Thus a mechanical supplement or substitute, for the function of the pretibials during this period is possible. As to which is the actuality, supplement or substitute, would seem to depend upon the severity of the spasticity present.

The result is either a partial or a total by-pass of the pretibial muscles. Stimuli to regional proprioceptors are kept to a minimum, if not eliminated, thereby reducing further excitation to the spastic tibialis anterior. The fact that the normally inactive plantar flexors have not been interfered with throughout this period, is most significant. The posterior springs also hold the foot in 2° to 3° of dorsiflexion throughout the swing phase. The force of the springs eliminates the need for the pretibials to sustain a position of dorsiflexion, so important to maintaining clearance between the foot and floor during swing phase.

2. The metal band is to be attached anterior to the uprights instead of the usual posterior calf band.

RATIONALE:

The purpose of the band is to stabilize the knee, from mid-stance to toe-off, by supplementing the weak quadriceps muscles. This band and the anterior stops in the ankle joints work in unison to check the tibia's forward progress beyond the mid-stance period. As the tibia presses against the band a counter force builds which prevents flexion of the knee. During the mid-stance period the gastrocnemius muscle is kept in an eccentric contraction by preventing the heel from raising while simultaneously extending the knee. By mechanically producing what is normal position, at its normal time, in the overall sequence of motions within the stance phase, further protection against the occurrence of genu recurvatum is provided.

3. The ankle joints are to be set in 22° of external rotation. The Lehneis-New York University Measuring Board is used to determine the amount of tibial torsion and toe-out the patient presents.

RATIONALE:

The mechanical ankle axis of the brace will then be congruent to the patient's anatomical ankle axis, i.e., 22° of external tibial torsion. This will ensure against any impingement of the normal transverse rotary motions of the tibia, caused by the wearing of the brace. This setting prevents the brace from introducing abnormal torque forces to the ankle and foot, with all that

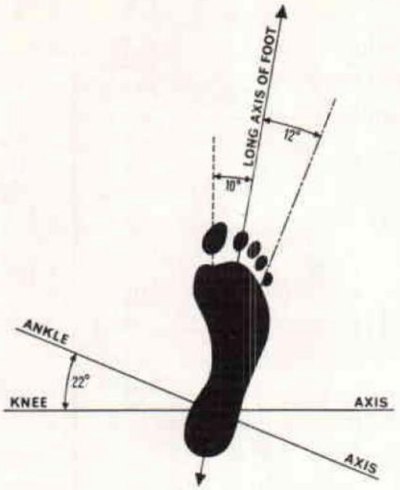



Fig. 3A
Transverse plane—(right foot—viewed from above)
Example of the anatomical alignment of the long axis of the foot (toe-out) to the knee and ankle axes.

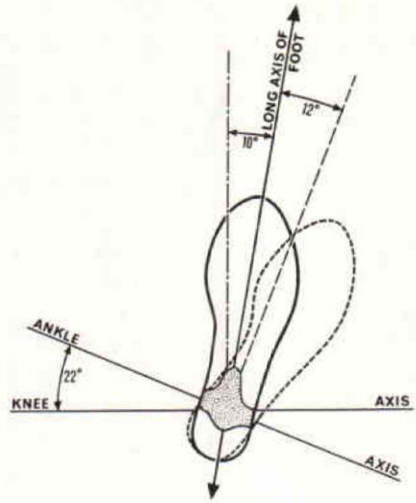



Fig. 3B
Transverse plane (left foot — viewed from below)
Duplicating nature's alignment — brace attachment set at 12° toe-in to ankle axis and 10° toe-out to knee axis. The dotted outline indicates the position in which the shoe, would be, in relation to the knee axis, were the 22° of tibial torsion put into the brace with the attachment fixed to the shoe in the patient's 10° of toe-out.

such torque forces imply to propriceptors in both regions.

4. The brace attachment (whether it be a solid stirrup or a receptacle for a split stirrup) is to be set at 22° of **toe-in** on the shoe.

RATIONALE:

This setting of the brace attachment to the shoe will duplicate the patient's anatomical relationship of the long axis of the foot (toe-out) to both his knee and ankle axes. (Figure 3A.)

The uprights are bent in a manner which places the ankle joint axis in a fixed 22° of external rotation. With the ankle joints thus aligned, were the brace attachments fixed to the shoe at the patient's anatomical toe-out of 10°, the result, when assembled, would be a shoe setting of 32° of toe-out to the patient's knee joint, as viewed in the transverse plane. (Figure 3B.)

In order to match nature's alignment, the following procedure is used:

PATIENT

A. 22° external tibial torsion

B. —10° toe-out.

—

12° (equals degree of toe-in to ankle axis)

BRACE AND SHOE

A. Brace must duplicate the full 22°.

B. Brace attachment is set in 12° of toe-in on the shoe

When the shoe is attached to the brace it will be in proper alignment, i.e., 10° of toe-out to the knee and 12° of toe-in to the ankle, as viewed in the transverse plane.

5. A rigid metal strip is inserted between the welt and the sole, throughout the length of the shoe.

Before insertion, its distal end is to be preshaped to set the forefoot in approximately 15°-20° of flexion as in the toe-off position.

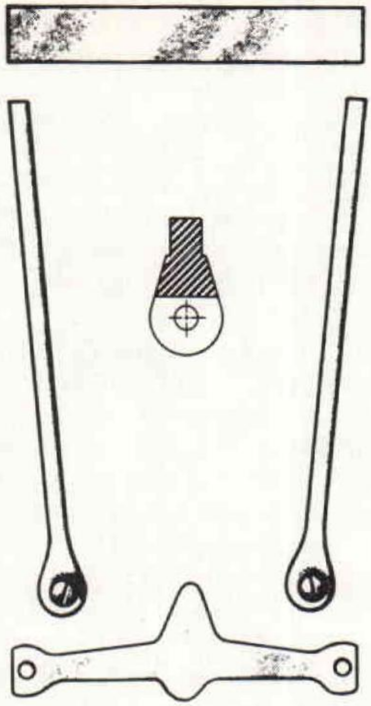
RATIONALE:

The purpose is threefold: 1) To utilize the entire length of the shoe as a more efficient resistance arm; 2) To reinforce the shoe; 3) to bypass the spastic tibialis anterior muscle by mechanically placing the forefoot in the toe-off position, thereby alleviating its need to be active at this time in the walking cycle. The posterior springs, at toe-off, provide some push-off force to start the leg into its forward acceleration during the swing phase.

6. A 3/16" to 1/4" 'rocker' bar is to be attached to the bottom of the sole of the shoe. The apex of the rounded rocker bar is to be placed immediately proximal to the metatarsal heads.

RATIONALE:

The rocker bar acts in conjunction with the anterior metal band and the anterior stops in the ankle joints. As the tibia's forward progress is checked at the mid-stance position by the anterior stops, a counter force is produced by the anterior metal band which prevents the knee from buckling. At this time in the walking cycle, the body weight is just beginning to rotate, in the transverse plane, forward of the lateral mid-line, having received its impetus from the push-off of the opposite limb. This same impetus is also rotating the body forward, in the sagittal plane and serves to 'trip' the body over the rocker bar, raising the heel and automatically placing the braced leg in the preset toe-off position. Thus the action of raising the heel and the placement of the foot in the toe-off position are produced mechanically, without using the musculature which would normally be required to accomplish these movements.



DOUBLE UPRIGHT BK BRACE
Limited Motion
FIG. 4

7. A cushion heel is used to replace the hard rubber heel.

RATIONALE:

The cushion heel's function is to reduce the sudden jolt (exceeding the body weight by 15-20 percent), which the limb receives at heel-strike, thereby reducing excitation to whatever spasticity may be present.

The design of a BK brace for a cerebral palsy patient who presents the common problem of a spastic gastrocnemius and accompanying knee flexion, would consist of the following available components:

1. Bilateral limited motion ankle joints and uprights. The anterior portion of the joints are to be rigid stops set slightly less than 90°, the same as the previous design. The posterior portion is to permit 15° of plantar flexion. (Figure 4.)

RATIONALE:

In the normal sequence of events during stance phase, the gastrocnemius is not involved in achieving foot-flat, i.e., the 15° of plantar flexion. Any attempt to prevent foot-flat from occurring, will force the gastrocnemius and all other plantar flexor muscles to go into an isotonic contracture following heel-strike, to overcome the resistance of placing the foot in the normal position to receive the weight of the body. In those cases where a plantar flexion stop is used and the calcaneous is successfully prevented from raising in the shoe when the gastrocnemius is spastic—the result is a force which will act to flex the knee. Again, the contradiction of the use of a plantar flexion stop to prevent equinus becomes evident. Posterior springs are not used because the patient possesses the full compliment of functional pretibials (though weakened due to constant overpowering by their spastic antagonist).

2. Anterior metal band.

RATIONALE:

Again, this band and the anterior stops in the ankle joints work in unison to check the tibia's forward progress beyond the mid-stance position. The previous rationale for the use of this band is still valid, although this patient has functional quardiceps. It should be noted that because of the tendency of a spastic muscle to lose its normal length, it seems practical to permit the gastrocnemius to perform the eccentric contraction which occurs between the foot-flat and mid-stance positions. (Figure 5.)

3. The ankle joints are to be set in external rotation equal to the external tibial torsion which the patient presents.

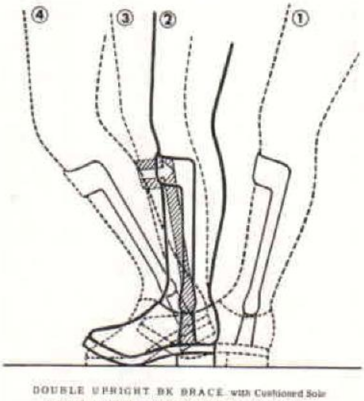
RATIONALE:

The previous rationale is still valid. However, as previously mentioned, no brace is presently available which will accommodate to the gradual 'developmental' increase of external tibial torsion in the growing child. The restriction of this aspect of growth which present-day braces impose, hopefully will be alleviated before too long.

a. Foot is plantar flexing toward the foot-flat position following heel-strike. Note the impact absorption through the compressed posterior portion of the cushion heel.

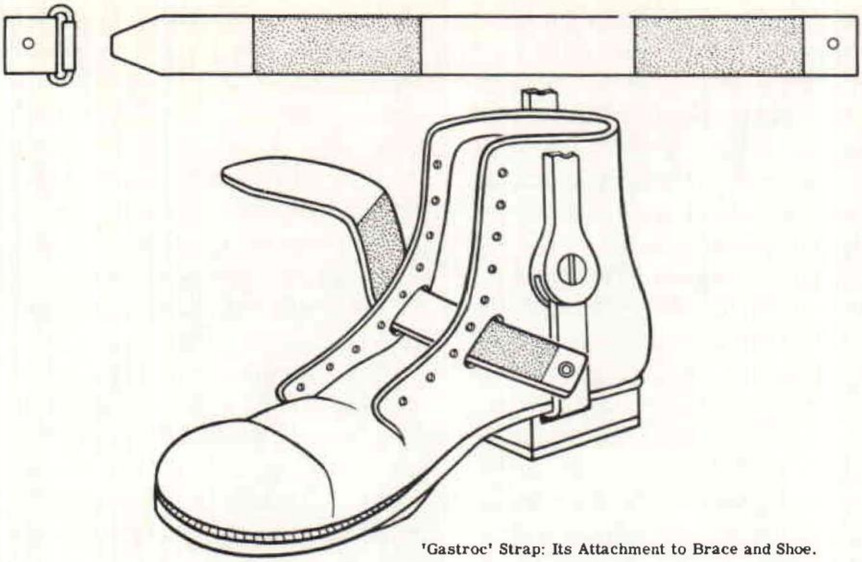
b. Mid-stance position: The limb in swing phase, along with the

A SCHEMATIC ILLUSTRATION OF "PROGRAMED" BRACE-TO-BODY DYNAMICS




DOUBLE UPRIGHT BK BRACE with Cushioned Sole and heel and "Rocker" Bar and Rigid Metal Sole Plate

FIG. 5



'Gastroc' Strap: Its Attachment to Brace and Shoe.

FIG. 6

body, has rotated in the transverse plane to the lateral midline. Note the stability of the knee at this period when the magnitude of downward vertical force is high. The preset toe-off positioning of the metal sole plate is evident.

c. Just before heel-rise: The body's center of gravity has now rotated in the transverse plane forward of the lateral midline. Note the stabilizing of the knee by the counter pressure of the anterior metal band. 2°-3° of forward motion allowed to the tibia by the anterior stops in the ankle joints permits normal knee flexion during this period.

d. The forward rotation of the body has 'tripped' over the rocker bar and placed the foot in the toe-off position in preparation for push-off.

4. The brace is to be fixed to the shoe to match the patient's anatomical requirements, as per the previously described procedure.

RATIONALE:

The previous rationale still applies and also relates to the remarks added to #3 immediately above, as the toe-out relationship would appear to be subject to change also.

5. A rigid metal plate is inserted between the welt and the sole, throughout the length of the shoe. Its distal end is to be preshaped as in the toe-off position of 15° of forefoot flexion.

RATIONALE:

The purpose remains threefold. The first two reasons presented in the previous rationale still apply. However, the reasons for placing the forefoot in a pre-set toe-off position are somewhat different: 1) Since normal heel-rise following the mid-stance position is prevented by the combined blockage of the anterior band and the anterior stops in the ankle joints, it appears reasonable to expect the patient's functioning pretibials will attempt to raise the heel. 2) The rigid plate stiffens the flexible sole of the shoe and resists both muscular and resultant forces. Therefore, the forced inactivity of the plantar flexors is not challenged by excessive activity of the pretibials at an unnatural time in a normal walking cycle. 3) The pre-set toe-off contouring of the shoe limits the efforts of the pretibials to a push-off force only, as the 'rocker bar' (see #6) serves as a mechanical substitute for their toe-off positioning activities.

6. A rocker bar is added to the sole of the shoe in the same placement as for the hemiplegic patient.

RATIONALE:

The same as the previous #6.

7. The hard rubber heel is replaced with a cushion heel.

RATIONALE:

The same as the previous #6. When additional 'shock absorption' is desirable, a ⅜" cushion sole is applied throughout the length of the shoe, and the cushion heel and rocker bar are added to it. When a cushioned sole is used, an equal thickness must be placed on the other shoe. When reduction of unwanted stimuli to the skin of the sole and heel, which is related to contact with the floor is desired, a ⅛" to $\frac{3}{16}$" cushion inner-sole may be placed inside the shoe. Whenever a cushion inner-sole is used a size larger shoe is necessary to ensure patient comfort.

8. A gastroc' restraining strap.

RATIONALE:

This velcro strap is pivotably attached on the solid, or split stirrup, below the ankle joint. It passes over the instep, through two slots cut below the eyelets on either side of the tongue, and passing through a metal loop (also pivotably attached on the opposite side, below the ankle joint) to fasten onto itself, either side of the instep (Figure 6). A $\frac{3}{16}$" x ¼" felt pad is cemented to the inner-sole of the tongue to prevent the velcro strap from cutting into the instep. A size wider shoe will allow room for the tongue pad.

The patient's foot is placed in the shoe while the brace is attached. The knee is flexed and the heel is checked to be sure it is in contact with the bottom of the shoe. The velcro strap is then passed through the metal loop attached below the ankle joint. A firm downward pressure is applied to the instep with one hand while the slack is drawn out of the strap. When the foot is firmly set against the bottom of the shoe, the velcro strap is fixed to itself on the metal loop side of the tongue. The shoe is then laced and tied and the loose end of the velcro strap is drawn over the laced instep and fixed to itself at the originating end of the strap.

The purpose of this strap is to insure that the gastrocnemius muscle cannot go into isotonic contracture as the tibia moves forward over the foot in the sagittal plane. The combined effect of this strap and the anterior metal band attached to the uprights force the gastrocnemius to stretch, thus limiting its action to an eccentric, or more clearly descriptive, an isometric contraction—the tibia's forward progress having been checked well short of its normal maximum range.

Although the preceding examples are confined to two specific biomechanical dysfunctions, the functional analysis approach is suggested as a means of analyzing orthotic problems in general, regardless of etiology, as they relate to walking. The technique appears to hold promise as a means of realizing the full potential of current knowledge, and in so doing, help to identify the areas in which future orthotic research would be most fruitful. It is hoped that the publishing of the preceding ideas will serve to excite the interest of those who are dedicated to improving the well-being of the handicapped.

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