Critique of Lower Extremity Bracing

by

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INTRODUCTION

Lack of progress and poor results in the field of lower-extremity Orthotics are evident today. Braces have changed little in fifty years, yet the introduction of new materials and new concepts should make possible the improvements which have failed to materialize.

This is even less tolerable since engineers now tell us that an exoskeleton is mechanically more effective than an endoskeleton, and that spacemen will someday wear artificial exoskeletons which will multiply the available power while reducing energy cost (1).

1. *The Key Problem: Knee Stability*

Regardless of diagnosis or condition, all paralyzed individuals today are provided with the same kind of brace, reason for this being that the key problem remains knee stability. Lower-extremity ortheses are nothing but glorified knee locks, slightly modified to suit individual tastes.

2. *Ambulation Without Brace*

During normal human locomotion, muscles of the lower extremity act upon the segments to accelerate and decelerate them; they also provide the "holding" power which locks the joints and provides stability. When the muscles are totally or partially paralyzed, "weakness" endangers stability and impairs control (2) (3).

2.1. When paralysis is not complete, the patient may sometimes continue to ambulate without a brace, by modifying his method of obtaining joint stability. For ex-

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ample, he can use recurvatum to lock the knee.

2.1.1. This method of ambulation increases energy consumption; when the patient "throws" forward his paralyzed limb, the shin accelerates rearward abruptly. It is deprived of power for deceleration and/or counter-acceleration, so that gravity itself must bring the shin forward past the vertical. This also results in considerable slowness of displacement (see 3.1).

2.2. Vertical displacement of the center of gravity of the body is influenced by the increased length of the lower extremity on the stance side. Once the knee is hyperextended, the patient must hoist his body mass higher than when the knee remains slightly flexed as physiologically desirable (see 10.3). Again, the result is higher energy cost (4).

3. *Ambulation with a Brace*

More severe cases need to wear a brace with a locked knee. The orthosis restores stability, but it creates complex problems of utilization.

3.1. During normal ambulation, forward acceleration of the thigh segment is counter-balanced by rearward motion of the shin. This bi-pendular action reduces the amount of muscle work by transfering angular momentum from thigh segment to shin segment, and vice-versa.

3.2. As soon as the brace is locked at the knee, the lower extremity is changed from a double pendulum into a single pendulum. The increased length resists the initiation of forward motion, according to the law of resistance to angular acceleration (5) (see 4.1).

3.3. A comparison of energy cost in ambulation with a free knee, then with a lock added, has been made (6) on a subject fitted with a conventional, unilateral brace without ischial seat. Energy cost remained constantly higher with the knee locked, the average increase being placed at +25.4%.

4.1. *Swing Phase on the Affected Side*

Once the foot is fixed in a neutral position, the lack of dorsiflexion results in a hip-toe distance greater than hip-heel. The lengthened limb forces the subject to elevate his pelvis to clear the ground; in this case, the amount of work performed increases in proportion to the height to which the C. G. is raised (7). Moreover, the pendular axis finds itself elevated with regard to the ideal position of positive Tredelenburg (4) (8). Any amount of foot drop makes the situation worse.

4.2. *Swing Phase on the Sound Side*

During normal ambulation, at heel strike the C. G. of the body is descending and must be reversed (8). If the lower extremity is rigid, the forward momentum carries the body over the foot; this slows down the body and fails to provide the knee flexion preparatory to contralateral swing phase. This increases energy cost (6) (9) (10).

4.3. A rational brace, making possible a near-normal swing phase while providing stability during stance phase is offered by the UCLA functional long leg brace (2). Thus it becomes possible to combine stability and joint freedom.

5. *Weight of the Brace*

The weight of the orthosis is concentrated in the distal part (knee and ankle joints, foot plate). This lowers the center of gravity of the pendular segment.

5.1. Whenever the center of gravity moves away from the rotational axis (in this instance the hip joint), the moment of inertia increases by a quantity proportional to the square of the distance mass-axis.

5.2. Time of swing of a pendulum is proportional to the square root of its length ($1/\sqrt{L}\cdot L = \sqrt{L}$ where L = pendulum length). The "unipendular" segment created by the knee lock slows down the motion of the braced extremity.

5.3. Once in motion, the braced lower extremity is submitted to increased pendular acceleration. The energy accumulated must be dissipated by the patient who, if paralysis of the gluteus maximus is present, performs some abnormal braking motion.

6. *Location of the Center of Gravity of Limb*

Weight itself is not as important as its distribution. This was demonstrated by a study concerned with prosthetic substitution of the lower extremity (11).

6.1. Lowering the center of gravity of a limb results in an increase of inertia (see 5.1). Inertia is the most significant obstacle to muscle action, in deceleration as well as acceleration. Using a weight sliding on a calibrated stick, Bresler (11) was able to record the influence of the location of limb center of gravity. He showed that energy cost increases in proportion to lowering of the center of gravity, inertia becoming proportionally greater.

6.1.1. The same author showed that inertia had more influence on energy cost than specific location of the center of gravity of the limb. Thus, the presence of a knee lock is a worse factor than is the weight of the brace itself.

6.2. Starting from theoretical premises, Staros (4) could calculate that, if the weight of the foot and shin sections in a prosthesis were halved, inertia would be reduced by 60% and energy cost by 40%. This should apply to orthotics as well. Even if lower extremity braces retain the same shape, their weight, at least, can be reduced through use of light alloys and plastic materials.

7. *Influence of Proper Alignment on Weight of Brace*

Steel uprights and thick leather corsets could be justified if the weight of the patient's body were borne by the brace. This is not true (2) (12). The weight is borne—with few exceptions—by the patient's own skeleton. The brace acts only to maintain the knee in an extended position; this is achieved by A-P contention.

7.1. Correct alignment is the

result of pre-tibial pressure combined with reactions at the heel and upper thigh levels. As long as the lower extremity is properly held, stress on the brace is minimal. But if vertical alignment is poor (loose pre-tibial band, for example), the subject "sits" in his brace and quickly destroys it.

7.1.1. Perfect alignment has made it possible to create the "Attelle Monotubulaire" (12) and the "Unibar" brace (13) (14), each utilizing a single external upright. As regards to weight, this should be getting close to Staros' hypotheses (Para. 6).

7.2. In addition to weight reduction, another advantage of the single upright brace is better alignment of mechanical knee and ankle joints, including tibial torsion along the vertical axis (see 9.2.2).

8. *Movement in Lower Extremity Joints*

Several complex movements take place in the joints of the lower extremity. As for mechanical joints, until now they allow only flexion-extension by rotation around a single axis (double-axis joints are rare, and again permit only flexion-extension).

8.1. *Hip Joint*. During ambulation, the femur articulates with the ilium:

8.1.1. in flexion, 35°+.

8.1.2. in extension, about 5°.

8.1.3. the amount of angular rotation has not been precisely measured, but it is essential to normal ambulation.

8.1.4. mechanical joint: flexion-extension only.

8.2. *Knee Joint*. The following movements take place (15) (16):

8.2.1. Flexion ± 70°.

8.2.2. Extension: neutral position is almost never reached, the knee remaining slightly flexed (5° to 20°) during stance phase.

8.2.3. Tibial rotation around vertical axis:

—at heel rise, 9° of internal rotation;

—at heel strike, 8° of external rotation.

8.2.4. Mechanical joint: knee locked in hyperextension, no flexion possible, no tibial rotation.

8.3. *Ankle Joint*. During ambulation, the following takes place (16):

8.3.1. At heel rise, ± 10° of dorsiflexion.

8.3.2. At heel strike, ± 20° of plantar flexion.

8.3.3. Movements of the subtalar joint:

—just before heel rise, 6° of inversion;

—just after heel strike, 5° of eversion.

8.3.4. Mechanical joint: dorsiflexion and/or plantar flexion either free or limited. No inversion or eversion possible.

9. *Problems of Alignments With Mechanical Joints*

Any alignment of a mechanical joint is a compromise. However, one must guard against gross oversimplifications, such as considering the knee joint as a hinge.

9.1. The anatomical knee joint combines hinge and sliding motions, the rotational axis changing in relation to the position of the femoral condyles. This constant migration was evidenced by an X-ray series, the conclusions to be later controlled on cadavers (17).

9.1.1. Ideal placement of the mechanical rotational axis at the knee joint is impossible today; the orthotist has no alternative but to make use of the best possible compromise.

9.2. At ankle level, the rotational axis is approximately perpendicular to the path of the body center of gravity; in this fashion the ankle is free to plantarflex and dorsiflex during lateral oscillation (18) (19).

9.2.1. The mechanical ankle joint should be aligned with the transverse axis of the anatomical joint. Placement of this axis is secondary to the amount of tibial torsion and not related to the more or less everted position of the foot.

9.2.2. Tibial torsion takes place during maturation of the individual, going from 2° in the newborn to 20° or 30° at about 7 years of age. This torsion on the longitudinal axis places the ankle joint in a position suited to bipedal locomotion (20). A measuring board makes it easier to correct for ankle alignment (21).

10. *Interference of the Brace with Basic Components of Gait*

Going through the basic components of gait, it becomes easy to note the abnormal factors introduced by lower extremity bracing of the conventional type (7) (22).

10.1. Pelvic rotation around the vertical axis, total of 8°: made impossible by pelvic bands and locked hip joints.

10.2. Pelvic tilt on the swing side, 5°: made impossible by the invariable length of the brace with knee lock.

10.3. Knee flexion at stance phase, about 15°: made impossible by the knee lock.

10.4. Knee and ankle action whose coordinated action eliminates brutal ascent and descent of body center of gravity—impossible because of the rigidity of the brace.

10.5. Lateral displacement of pelvis, bringing center of gravity of the body on top of the foot: often compromised by improper brace alignment which keeps the foot too far away from mid-line.

10.5.1. Importance of lateral motion of the pelvis: during swing phase the center of gravity projection comes very close to the center of the heel on the stance side (23).

10.5.2. The need to reduce the lateral excursion of the pelvis explains the presence of knee valgus in the architecture of the normal lower extremity.

10.5.3. It is imperative to respect this alignment, and not to force the lower extremity to conform to a brace built straight, as is often the case.

CONCLUSION

Braces for the lower extremity have changed little since the days of Von Hessing (1839–1918). By contrast, prostheses are improving rapidly. Thus it seems that Orthotics should borrow as much as possible from Prosthetics and make use of the same scientific evidence. It is, after all, a paradox to see that a man who has lost his leg can walk with only a trace of limp, when a paralyzed person whose skeleton, at least, is intact is immediately conspicuous in a crowd and wastes considerable amounts of energy to ambulate.

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