Orthopedic Rehabilitation

6.1. Introductions:

The word orthosis derives from the Greek orthos, meaning “to straighten.” An orthosis is an orthopedic device that provides functional stability to a joint or prevents, corrects, or compensates for a deformity or weakness.

Typically, this is accomplished through external bracing (although the term brace is somewhat deprecated because of institutionalized stereotypes and implications of static fixation), whereas orthoses also provide dynamic joint control.

An orthosis can be as simple as an off-the-shelf, prefabricated shoe insert that one could purchase at a pharmacy or department store, or something more complex, such as a reciprocating gait orthosis usually consisting of custom-molded plastic solid ankle and thigh shells connected via bilateral uprights with locking knee joints, dual cables for controlling alternating gait, and gas-filled struts or springs to aid in knee and hip flexion.

6.2.1 Classification

Standard nomenclature for orthoses varies, depending on the type, i.e., upper extremity vs. spinal vs. lower extremity. Names for orthoses originate from the joint or joints they encompass (e.g., wrist orthosis), the function provided (e.g., reciprocating gait orthosis), condition treated (e.g., tennis elbow splint), appearance (e.g., airplane splint and halo brace), or person who designed it or place where it was designed (e.g., Milwaukee brace and Jewett orthosis).

In addition, organizations such as the American Society of Hand Therapists (ASHT) and International Standards Organization (ISO) have developed standard nomenclature for orthoses. The current method of naming an orthosis is by creating of an acronym from the English words for the joints that the orthosis crosses, in sequence from proximal to distal.

The letter “O” is appended to signify orthosis. For instance, an orthosis that covers the foot and attaches to the leg to compensate for weakened ankle dorsiflexors (drop foot) would be called an ankle–foot orthosis, or AFO. Often, additional letters are added, describing the device, such as AFO–SA (solid ankle) or AFO–PLS (posterior leaf spring).

6.2.2. Function

Orthoses are classified as static or dynamic. Static orthoses are designed to prevent or limit motion and have no moveable parts. Dynamic orthoses are designed to facilitate movement and have one or more movable parts. The three general functions of orthoses are categorized as (1) immobilizing, (2) restrictive, and (3) mobilizing.

Immobilizing and restrictive orthoses, both provide static support. Immobilizing orthoses prevent any movement in the joints involved, whereas restrictive orthoses limit movement in a specific aspect of joint range of motion. The static support helps to reduce stress and maintain joint alignment; prevent deformities and soft tissue contractures; scar reduction; provide rest to reduce inflammation and pain; positioning to facilitate proper healing; and protection against further injury.

Mobilization or dynamic orthoses are designed to increase range of motion (stretch soft tissue contractures) and assist muscle weakness or spasticity to improve function. These orthoses are also used for exercise to improve the range of motion and strength.

6.3. Biomechanical Principles

6.3.1 Three-Point Pressure System

Orthoses act to restrict joint motion via a three-point pressure system. Although other pressure systems exist, this is the most basic one. The terminology three-point force is also used to describe this system; however, pressure is preferred as it reminds us that it is an applied force distributed over an area. The three-point pressure system generally consists of a principal force acting at or near the affected joint, opposed by two forces, one proximal and the other distal to the joint, to stabilize the joint

6.3.2 Leverage

Leverage goes hand in hand with the three-point pressure system. Leverage is the mechanical advantage of a force applied at a distance from a fulcrum. The moment of this force causes the body to tend to rotate about the fulcrum. The larger the perpendicular distance of the force to the fulcrum, the greater the moment generated. To stabilize the joint, the moments from all applied forces (including gravity and inertia) must sum to zero. By increasing the lever arm length, the force necessary to stabilize the joint can be reduced, thus increasing comfort

6.3.3 Ground Reaction Force

The ground reaction force, or force generated by the floor on the patient due to gravity and body accelerations, is also important in controlling joint motion.

The ground reaction force can be utilized to stabilize a joint more proximal to the orthosis. When the foot contacts the ground during gait, it produces a moment about each of the joints of the lower extremity. Depending on the line of action of the force, the moment could be in flexion, extension, or through the joint center, causing no moment. A heel cutoff on a shoe can compensate for weak quadriceps muscles by shifting the contact point forward and the direction of the ground reaction force closer to the knee center, thus reducing the flexion moment about the knee. Alternatively, an AFO–SA with an anterior band provides a posteriorly directed force at the tibia that limits knee flexion by resisting forward motion of the tibia.

6.3.4 Axial Forces

Axial force is a force directed along the long axis of the bone. Reduction of axial forces in lower limb fractures is typically via crutches or in unweighting AFOs that unload the ankle or foot by transferring the weight through the orthoses.

6.3.5 Pressure

In general, it is beneficial to distribute the forces the orthosis applies to the body over a large area. This minimizes the stress on soft tissue. An AFO with a custom-molded plastic calf shell would be more comfortable than a leather–metal AFO; however, this would be contraindicated in cases of edema and dermatitis or hot climates.

6.3.6 Shear Stress

It is important to minimize shear stress at the interface of the patient and orthosis. Shear stress is typically caused by tangential forces applied to the load-bearing surface of the body. These shear forces can cause motion between the underlying skin, muscle, and fascia and the orthosis.

The deformation may restrict blood and lymph flow, causing ulcers and tissue damage. Shear stresses can be reduced by optimal design, proper fit and alignment of the orthosis, and use of slippery elastic padding at the patient–orthoses interface

6.3.7 Creep

Creep is the time-dependent strain, or change in shape, of a material due to exposure to stresses and loading. This creep occurs in a matter of seconds or weeks, depending on the stiffness and viscoelastic properties of the material. Creep occurs in both muscles and soft tissues bearing load due to the orthosis, and is critical in the design and fit of orthoses.

6.4. Materials Selection

Plastics are the most common material in modern orthoses. Plastics are divided into two major categories, thermoplastics and thermosets. Thermoplasts become pliable when heated and rigid when cooled. Thermoplasts can be reheated and reformed.

Thermosets can be worked into shape when heated; however, they develop a permanent shape once cooled. Thermoplasts that become workable under temperatures of 80◦C are considered low-temperature thermoplasts and, with care, can be molded directly to a body segment. Because of limited strength and fatigue resistance, low-temperature thermoplasts are found primarily in fracture splints and upper extremity orthotics. Thermoplastics workable at temperatures over 80◦C are called high-temperature thermoplasts and must be shaped over a mold or cast. They are stronger and more resistant to creep than their low-temperature counterparts, and are therefore used in more permanent and higher-load-bearing orthoses.

High temperature thermoplasts can be injected with air or other gases to form soft foam padding and liners in many orthoses. Thermosetting plastics are made by curing a polyester or epoxy resin. The resin is poured over fabric such as nylon, fiberglass, or carbon fiber, and layers are laminated over a mold. The resulting material can have strength-to-weight ratios comparable to steels and must be cut, machined, ground, or sanded to modify its shape. Thermosets are typically used where strength is of importance; however, the use of thermoplastics with carbon fiber has limited their use.

6.5 Spinal Orthoses

The appropriate orthotic prescription to address pathology of the spine (i.e., back pain, spine deformity, or injury) requires an understanding of the biomechanics and kinetics of the spine. The spine is composed of 7 cervical, 12 thoracic, 5 lumbar, and 5 fused sacral vertebrae. The articulation of the vertebrae with supporting ligaments, muscles, and other skeletal elements is responsible for the unique characteristics of each of the four regions of the spine. Movement occurs between sequential vertebrae and is described as having six degrees of freedom, with rotation about the three orthogonal axes and translation through the same axes. Muscles attached to the vertebrae act to extend, flex, rotate, and laterally bend the spine. The sum of intervertebral movements provides a gross functional range of motion. This flexibility makes the spine vulnerable to injury and degeneration. A spinal orthosis is prescribed to protect an injured segment, limit intervertebral movement, limit gross movements of the spine, and apply forces to correct or inhibit the progression of some deformity.

There are four general curves along the spine—the cervical and lumbar spines are lordotic (concave posteriorly) and the thoracic and sacral spines are kyphotic (convex posteriorly). The intervertebral discs make up 25 to 30% of the total spine length. Load bearing of the spine consists of transferring the compressive force through the individual vertebrae and between adjacent vertebrae through the intervertebral disc. The disc, composed of a fibrous annulus and gelatinous inner layer, has specific viscoelastic properties that allow it to dampen the transmitted forces. Injury to either the skeletal components or to the surrounding musculature may create instability, resulting in pain, degeneration, and deformity.

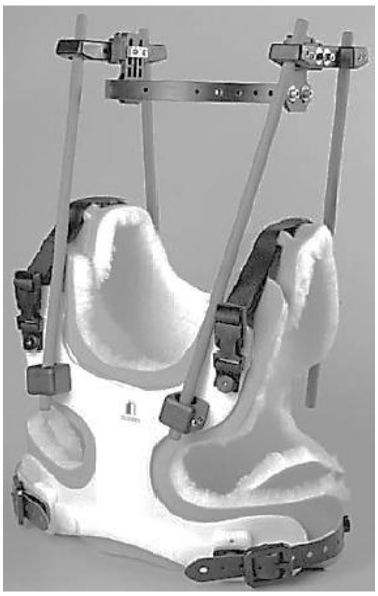
The spinal orthosis is designed to address this instability. The optimal spinal orthosis design is made of material that is rigid enough to control motion at the particular vertebral segments while minimizing discomfort. Three-point systems are used in alignment of the spine, with the corrective force midway between the opposing forces. The efficacy of spinal orthosis is inversely related to the distance between the inner surface of the orthosis and the spine. The angles between the axis of rotation of the vertebral segment of interest, the edge of the brace, and the long axis of the spine are important factors in designing a spinal orthosis. This angle is affected by both the thickness of the tissue and the length of the brace.

6.5.1 Cervical and Cervical Thoracic Orthoses

The cervical spine segment is very flexible, based upon the shape of the individual vertebrae and their articulation with adjacent vertebrae. Flexion, extension, lateral bending, and axial rotation are the movements of this segment. Cervical orthoses (CO) are divided into soft and hard orthoses. The most common soft cervical collar is made of foam and has a stocking sleeve. The soft orthosis does not provide control of the cervical segment; however, it does serve as a proprioceptive reminder to the patient to avoid excessive motion. The hard cervical collar is available in a variety of prefabricated models. The hard orthoses control cervical motion in the sagittal plane via the mandibular and occipital pads. These collars have poor control of lateral flexion and axial rotation. Superior control of cervical segment motion is possible by attachment of metal posts to the hard collar, which is then attached to a pad that rests on the shoulders. Greater vertebral segment control can be provided by extending the orthosis to involve the thorax, thereby providing additional leverage to control cervical spine motion. This extension results in a cervical thoracic orthosis (CTO), the most commonly prescribed one being the SOMI (sternal occipital mandibular immobilizer) (Figure).

This orthosis consists of a sternal plate, shoulder pads, mandibular and occipital pads, and bars. This wearer maintains lumbar flexion.

The next CTO, and considered the most invasive, is the HALO orthosis (Figure 2). This orthosis provides motion control in all three planes, and consists of a ring fixed to the skull with a series of pins. The ring is connected via bars to a rigid jacket. This degree of control makes this orthosis the preferred one to allow for fracture healing; however, complications include pin site infections, slippage of pins, and pain and discomfort interfering with the activities of daily living



6.5.2 Thoracolumbosacral and Lumbosacral Orthoses

The thoracolumbosacral orthosis (TLSO) and the lumbosacral orthosis (LSO) are typically prescribed to address deformity, fractures, and musculoskeletal back pain. Back pain is second only to cough as the presenting chief complaint to the primary care physician. Over 80% of people will experience low-back pain, and fortunately, more than 85% of these will resolve within 1 year. A variety of orthoses have been prescribed, ranging from the lumbosacral corset to the custom-molded thermoplastic TLSO. In addition to the orthosis prescription, an exercise program to strengthen the supporting spinal musculature, as well as proper lifting techniques, have proven effective.

The corsets serve as both a proprioceptive reminder to limit motion and provide warmth to the injured area, but they provide limited motion control (Figure 3).

FIGURE 3.

Some corsets incorporate metal stays to provide increased rigidity, as well as thermoplastic inserts or air bladders. LSOs incorporate thoracic and pelvic bands that encompass the torso at each respective level. Paraspinal bars are shaped to follow paraspinal musculature, and lateral bars are along the midaxillary trochanteric line. Using these basic principles, a variety of orthoses are created and adapted according to the plane of motion that needs to be controlled.

Sagittal control is provided by an LSO (also known as chairback) consisting of a thoracic band, pelvic band, and two paraspinal bars.

Two three-point systems are utilized. To control motion in the sagittal and coronal plane, lateral bars are added to the chairback orthosis, in effect, adding an additional three-point pressure system in the coronal plane. To provide control in the extension coronal plane, oblique bars are added, resulting in free flexion with limited spinal extension.
The TLSO incorporates the thorax, with the same principles; the basic design may be modified based on the level and motion control needed. For flexion control, the orthosis is designed with a metal frame, with pads at the pubic bone, sternum, and at the lateral midline of the trunk. The Jewett orthosis is the archetype, with a three-point pressure system, two directed posteriorly and one directed anteriorly (Figure .4).

FIGURE .4

The result is reduced lumbar flexion with full extension. Motion in the sagittal plane is controlled by modifying the TLSO by incorporating paraspinal bars, pelvic and interscapular bands, and axillary straps. Two three-point systems are demonstrated, with the interscapular strap providing anterior force and the axillary straps providing posterior-directed force. The sagittal coronal movement may be controlled with the combination of thoracic, pelvic and interscapular bands, axillary straps, and both paraspinal and lateral bars.

6.5.3 Cervicothoracolumbosacral Orthosis

No discussion of spinal deformity would be complete without discussing scoliosis, control of this progressive spinal deformity being the ultimate test of design, and clearly demonstrating the three-point model of orthoses. Scoliosis is a disorder resulting in progressive spinal deformity, the most common cause of which is idiopathic.

The biomechanics of progression of the deformity is described by Euler's theory of elastic buckling of a slender column. In Euler's theory, a straight flexible column, fixed at the base is placed under an axial load. There is some threshold value of the force beyond which the column buckles. In much the same way, as the child ages, the spinal column lengthens, and with associated weight gain in the upper extremities and trunk, the aforementioned threshold is achieved, and the spinal curvature progresses.

The comparison is an imperfect one, as unlike in the theory, in clinical practice the critical load (threshold axial force) is correlated to the degree of spinal curvature, large curves having lower critical loads; and the deformation is permanent even with removal of the axial load. The orthosis designed for treatment of scoliosis has three functions: (1) end-point control, (2) transverse support, and (3) correction of the curve. The standard orthosis that demonstrates this is the Milwaukee brace (cervicothoracolumbosacral orthosis, CTLSO) (Figure 5).

FIGURE .5

End-point control is provided by pelvic attachment to stabilize the base of the spine and a neck ring to keep the neck in line with the pelvis. A mandibular and occipital pad provides longitudinal distraction, while a lateral pad is placed on the convex side of the segmental deformity. Orthotic management of scoliosis is indicated in the management of those with spinal segment curves ranging from 20 to 30◦. Surgical correction of the spinal deformity is recommended for curvatures greater than 40◦, as the amount of corrective force required by the orthosis would be intolerable. The Milwaukee brace is the only CTLSO used in the treatment of spinal deformity; lower-profile orthoses, such as the Miami TLSO, are more desirable by patients because of comfort and cosmesis. The TLSO does not offer the same segmental control as the CTLSO. The basic design of three points of contact is demonstrated by the spinal orthosis, which is an excellent nonoperative intervention to reduce pain, protect a vertebral segment, and reduce and prevent progression of deformity.