1996

An Overview of the Prescription of Orthotics for Abnormal Subtalar Joint Pronation

Kari Rafteseth
University of North Dakota

AN OVERVIEW OF THE PRESCRIPTION OF ORTHOTICS FOR ABNORMAL SUBTALAR JOINT PRONATION

by

Kari Rafteseth
Bachelor of Science in Physical Therapy
University of North Dakota, 1995

An Independent Study

Submitted to the Graduate Faculty of the

Department of Physical Therapy

School of Medicine

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Physical Therapy

Grand Forks, North Dakota
May
1996

This Independent Study, submitted by Kari Rafteseth in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

(Faculty Preceptor)

(Graduate School Advisor)

(Chairperson, Physical Therapy)

PERMISSION

Title An Overview of the Prescription of Orthotics for Abnormal Subtalar Joint Pronation

Department Physical Therapy

Degree Master of Physical Therapy

In presenting this Independent Study Report in partial fulfillment of the requirements for a graduate degree from the University of North Dakota, I agree that the Department of Physical Therapy shall make it freely available for inspection. I further agree that permission for extensive copying for scholarly purposes may be granted by the professor who supervised my work or, in his absence, by the Chairperson of the department. It is understood that any copying or publication or other use of this independent study or part thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and the University of North Dakota in any scholarly use which may be made of any material in my Independent Study Report.

Signature Kari Rafteseth

Date 4/15/96

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

I would like to say thank you to my parents and my brother, Karl, for being supportive and understanding during my college years. I would also like to thank Daniel for being there for me and helping me when times got tough. Lastly, thank you to my friends. You are all very special to me!

ABSTRACT

The foot and ankle are a complex set of joints that are susceptible to various types of dysfunction, including abnormal subtalar joint pronation. An option for treatment of this problem that may be used is the prescription of orthotics. An orthotic is used to assist the foot in functioning properly and to prevent damage due to malalignment.

In this literature review, the anatomy and biomechanical function of the subtalar joint are discussed. The structure of the other joints of the foot and ankle are also mentioned. Several etiologies of abnormal pronation are discussed. In addition, changes in structure and function that may occur due to abnormal subtalar pronation are considered. Furthermore, materials used in fabricating orthotics and the methods of application of these materials are examined. The effectiveness of orthotics for abnormal subtalar joint pronation is also considered.

CHAPTER I

INTRODUCTION

The foot and ankle are a very complex system of joints which must work together to allow normal and efficient movement to occur. The function of the entire lower extremity is affected by the alignment of the bones, ligaments, and muscles that make up the joints of the foot and ankle. If a change occurs in the alignment of the foot and ankle or if a deformity is present, treatment with foot orthotics may be necessary.

One change in the alignment that may influence the function of the lower extremities and require treatment with orthotics is abnormal or excessive pronation of the subtalar joint. One of the main objectives of treatment with orthotics is to reduce the amount of abnormal pronation occurring at the subtalar joint.[1,2] Abnormal pronation at the subtalar joint may occur for several reasons. Among them are congenital defects and acquired deformities.[3(p32)] Any of these may require treatment with the prescription of foot orthotics.

Variations in the literature exist regarding methods of prescribing orthotics for abnormal subtalar joint pronation. Information included in the literature is quite diverse and may include options for the selection of materials for orthotics, types of orthotics and application methods, and the effectiveness of the orthotics.

There are many materials with several different properties used in the fabrication of orthotics. In addition, each group of materials has different prescriptive uses depending on the patient.[4,5] Additional materials such as posts can also be incorporated into the orthotic during fabrication in order to align the foot in "a more functional position."[6(p41)] However, exact locations and amounts of posting material are variable. The literature also shows conflicting results concerning the effectiveness of orthotics in treating abnormal subtalar joint pronation. However, results are generally favorable, as Gross states "problems related to pronation are more amenable to orthotic treatment than those of the cavus foot."[2]

The purpose of this review of the literature is to describe various components of the prescription of orthotics for abnormal subtalar joint pronation. Physical therapists may treat patients with abnormal subtalar joint pronation who would benefit from foot orthotics. Therefore, this information will be important for physical therapists, regardless of the clinician who makes the original prescription of the foot orthotic. Topics in this literature review include a discussion of the anatomy and biomechanics of the foot and ankle, etiologies of abnormal subtalar joint pronation, changes in biomechanical function that may occur as a result of abnormal subtalar joint pronation, selection of materials used in the prescription and fabrication of orthotics, application of those materials, and the effectiveness of foot orthotics in the treatment of abnormal subtalar joint pronation.

CHAPTER II

ANATOMY AND BIOMECHANICS OF THE FOOT AND ANKLE

Anatomy

There are numerous articulations in the foot and ankle, including the talocrural joint, the subtalar joint, the midtarsal joint, the tarsometatarsal joints, and the metatarsophalangeal joints.[7(p8),8] Each joint has a specific function and must combine its capabilities with the abilities of the other joints in order to produce a functional foot.

The talocrural joint is composed of the tibia, the fibula, and the talus.[8(p381),9] The joint axis runs in a distal and posterolateral direction from the medial malleolus to the lateral malleolus.[8(p385)] The talocrural joint allows dorsiflexion and plantarflexion movements to occur.[8(p381)]

The subtalar joint is composed of the talus and the calcaneus.[7(p14),10(p31)] The axis of the subtalar joint runs obliquely in an anterior, dorsal, and medial direction; however, sources differ regarding the exact location of this axis. In the transverse plane, the joint axis can be located within a range of 4° to 47° medial to the midline.[11(p67),12(p258)] (Fig. 1) Twenty-three degrees medial to the midline is one of the most commonly cited locations of this portion of this axis[7(p14),11(p67)]; however, 16° has also been cited.[8(p390),13(p22),14(p37)] The joint axis in the sagittal

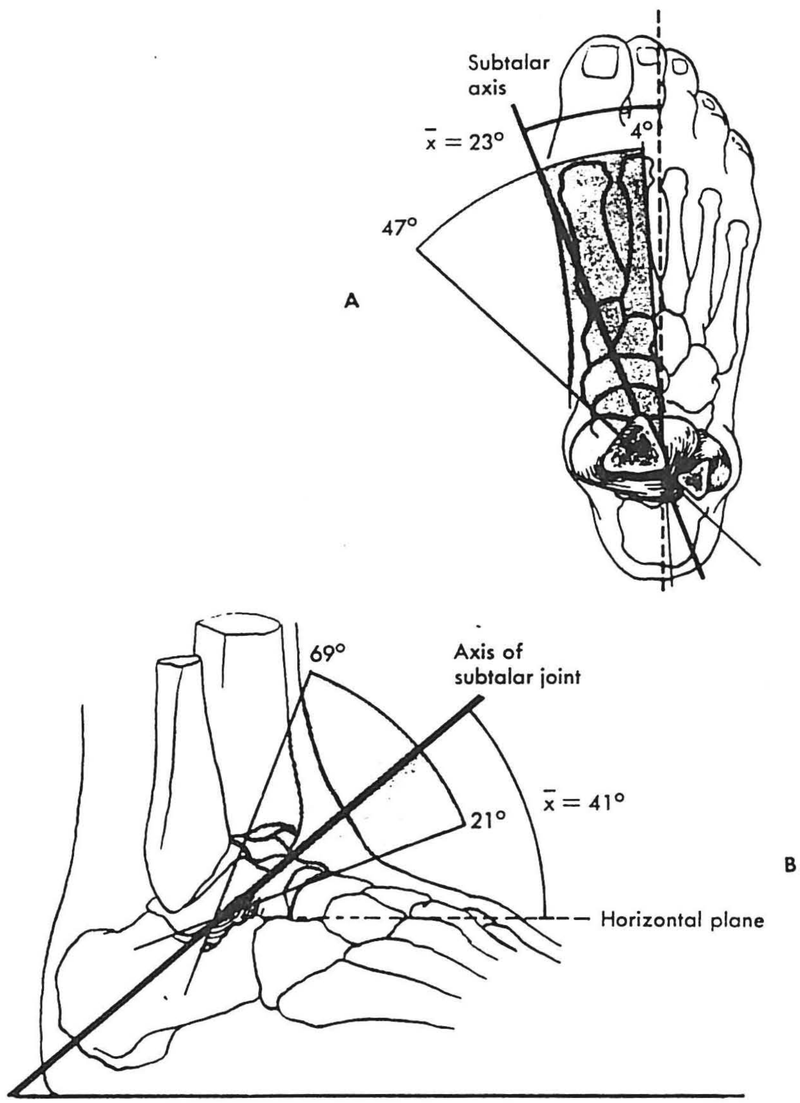

Fig.--Location of subtalar joint axis. A. Axis in transerse plane. B. Axis in sagittal plane.

Adapted with permission from Mann RA. Biomechanics of the foot. In: Atlas of Orthotics: Biomechanical Principles and Application. St. Louis, Mo: The CV Mosby Company; 1975:260.

plane is also variable; it can be located within a range of 21° to 69° superior to the horizontal plane.[12(p258)] Forty-one degrees superior to the horizontal plane is a common location of this portion of the subtalar joint axis[12(p258)] (Fig. 1); however, axes at 42°[7(p14),8(p390),13(p22)] and 45° are also cited as common locations.[14(p38)] The subtalar joint allows pronation and supination movements to occur.[7(p14)] These motions will be discussed later.

The midtarsal joint articulates at the talonavicular and calcaneocuboid joints.[7(p19),8(p396)] Movement occurs at the longitudinal axis and the oblique axis, providing pronation and supination motions of the foot.[8(p397)] The tarsometatarsal joints are responsible for portions of the movement in the forefoot region.[8(pp401-402)] In addition, the metatarsophalangeal joints are primarily responsible for flexion, extension, abduction, and adduction motions of the proximal toes.[8(p403)]

As mentioned previously, the talus and the calcaneus articulate in the subtalar joint.[10(pp31-32)] The talus is a roughened structure with three facets. The calcaneus also has three facets which articulate with those of the talus. The posterior facet of the talus articulates with the posterior facet of the calcaneus, while the middle and anterior facets articulate with the corresponding facets on the calcaneus. Additionally, the talus articulates anteriorly with the navicular bone. The region near the talus is also very vascular in nature.[15] Vascular supply to the talus and the subtalar joint is provided by the posterior tibial artery, the anterior tibial artery, and the peroneal artery.

Support of the subtalar joint can be attributed to the soft tissue surrounding the joint, including numerous ligaments, the medial and lateral longitudinal arches, and the surrounding musculature. The talus serves as the attachment for many ligaments which support the foot and ankle complex.[15,17] Ligaments which attach to the talus include the deltoid ligament medially and the anterior talofibular and posterior talofibular ligaments laterally. Furthermore, the talocalcaneal (interosseus) ligament holds the talus and the calcaneus together and is considered the primary ligament of the talocalcaneal articulation.[15,18] Another important ligament is the spring (plantar calcaneonavicular) ligament, which helps to maintain the position of the head of the talus.[15,17] The joint capsule and the flexor and extensor retinacula also support the subtalar joint.[10(p32)] Other soft tissue supporting the region of the medial longitudinal arch include the long and short plantar ligaments and the plantar aponeurosis.[8(p407)]

The location of the musculature in the foot and ankle determines the function of each specific muscle. Muscles that are medial to the subtalar joint axis perform inversion or supination and muscles lateral to the subtalar joint axis perform eversion or pronation.[12(p262)] Muscles that cross the ankle joint do not attach to the talus; however, they do influence the movement of the subtalar joint. Motion occurring at the transverse tarsal joint, the talocrural joint, and the talonavicular joint also influence motion occurring at the subtalar joint.[10(p31),11(p65)]

Muscles that perform pronation and supination affect motion occurring at the subtalar joint, as noted previously. The primary muscles which perform pronation, or eversion, are the peroneus longus, peroneus brevis, peroneus tertius, and extensor digitorum longus. The primary muscles which perform supination, or inversion, are the tibialis anterior, tibialis posterior, flexor hallucis longus, flexor digitorum longus, and the triceps surae muscles.[15,19] When overpronation is present, muscles which supinate the foot must work harder to maintain an arched or supinated position of the foot during gait and other activities. Therefore, in the event of overpronation, overuse injuries such as posterior tibialis tendinitis may occur.[20,21]

Biomechanics

The prescription of foot orthotics for overpronation is dependent on many factors, including the biomechanics of the foot and ankle. Knowledge of the normal biomechanics of the foot and ankle is necessary to determine the abnormalities that may be present and how to influence them through the prescription of orthotics. Therefore, understanding the biomechanics of the foot and ankle is an important part of the decision regarding the type of orthotic a patient will use.

Clinical problems in the foot and ankle can be traced back to the evolutionary changes that have occurred. The function of the feet of our ancestors was considered grasping, whereas the feet of humans today are considered propulsive.[22] In addition, humans have become bipedal and walk upright.[22,23(p31)] Changes in the anatomical biomechanical structure of the foot and ankle that make upright walking possible include the enlargement of the calcaneus and the development of a medial longitudinal arch.[22] The calcaneus has increased in size in order to increase the lever arm length of the calf muscles for propulsion. The formation of a medial longitudinal arch is important because it has become a primary load-bearing structure during upright walking.[24] In addition, structures surrounding the medial longitudinal arch are forced to absorb the additional forces of upright walking. Thus, the function of the foot has changed drastically over time.

Several sources in the literature describe the current function of the foot. According to Saltzman and coworker,[24] there are five main functions of the foot. First, the foot should have the ability to endure loads to which the foot is exposed during weight bearing activities. Second, the foot provides propulsion of the body using leverage provided by the action of the triceps surae muscle. Third, it acts as a shock absorber during gait. Fourth, the foot ensures balance and protection against falling by providing a steady foundation for the body. Lastly, the foot provides protection by receiving and transmitting sensory information about the environment to the rest of the body.

There is agreement in the literature regarding the fact that the foot needs to be supportive yet flexible to accommodate uneven terrain.[*] The literature also agrees that the foot needs to be rigid at other time to aid in propulsion. As McCulloch and colleagues[1] state, "movement of the foot from a mobile adaptor

---

* References 1, 11 (p65), 12 (p257), 13 (p19), 24, 25 (p450), 26 (p85)

to a rigid lever for propulsion depends on the balance between pronation and supination of the subtalar joint during the appropriate portions of stance." Therefore, the two major functions of the foot that are frequently discussed are support and propulsion.[11(p65),13(p19)] Support is provided through adaptation of the foot to uneven terrain.[25(p85)] Furthermore, support maintains the stability of the foot on uneven terrain. Conversely, propulsion is necessary to advance the body forward using the foot as a rigid lever. All of the aforementioned functions are important aspects of gait.

Pronation and supination are normal components of gait.[27] The average amount of pronation and supination in a normal foot ranges from 10° to 60°.[10(p37)] However, if either motion occurs in an excessive amount or at an improper time during gait, the movement becomes abnormal.[20,27-30] Abnormalities may also be occurring due to a deformity in the lower extremity.[20]

Pronation at the subtalar joint is a triplanar motion and consists of eversion, dorsiflexion, and abduction.[27,31-34] Eversion can be described as the movement of the calcaneus away from the midline.[12(p258)] Although the terms eversion and pronation are often used interchangeably, the term pronation is more appropriate for this literature review. Although pronation and supination take place primarily in the subtalar joint, the talocrural joint assists in the extremes of motion.[10(pp36-37),35] Additionally, the subtalar joint assists with dorsiflexion and plantarflexion movements at the extreme ends of the range of motion.

During weightbearing, rotation forces at the tibia are converted into pronation and supination in the subtalar joint and vice versa.[11(p68),12(p257),36(p218)] Movement at the subtalar joint is produced through external forces such as ground reaction forces or internal forces such as muscular contraction.[37] The purpose of this movement is to prevent injury to the foot or lower extremity during weightbearing and gait. Specifically, internal rotation of the tibia converts to pronation or eversion at the subtalar joint and external rotation of the tibia converts to supination or inversion at the subtalar joint.[2,23(p37)] Calcaneal eversion and internal rotation of the tibia occur during the first 12% of the gait cycle, followed by calcaneal inversion and external rotation.[14(p34)]

Pronation and supination also cause motions in the midtarsal joint to occur. Pronation leads to parallel alignment of the midtarsal joint axes, which increases motion of the foot. Supination leads to a locked position of the midtarsal joint axes, which decreases motion of the foot. Therefore, rotation of the tibia, movement of the subtalar joint, and movement of the midtarsal joint are related to each other.**

Sixty percent of the gait cycle consists of the stance phase in which weightbearing takes place, while 40% of the gait cycle is spent in swing phase without weightbearing.[23(p36)] During gait, the foot and ankle provide both stability and mobility. The joints of the foot and ankle change position many times during

---

** References 2, 8 (pp 392-393), 11 (p 68), 23 (pp 38-39) the stance and swing phases of gait.[38] At the beginning of the stance phase of gait, the position of the ankle at heel strike is neutral or 0°, followed by immediate progression to 15° of plantarflexion during foot flat. The anterior leg musculature is active in order to eccentrically control the speed of movement into plantarflexion. Between foot flat and midstance, the foot reverses its direction and begins to dorsiflex to approximately 10°. During this phase of gait, the soleus and gastrocnemius eccentrically control forward motion of the tibia. The ankle continues to dorsiflex to 15° between midstance and heel off, while the gastrocnemius and soleus maintain control of the tibia through eccentric control. In the last portion of the stance phase, from heel off to toe off, the ankle moves from its dorsiflexed position to 20° of plantarflexion. Muscle activity includes the gastrocnemius, soleus, peroneus brevis, peroneus longus, and the flexor hallucis longus, all of which plantarflex the foot during toe off.

The position of the foot and ankle also varies during the swing phase of gait.[38] During acceleration, the foot is dorsiflexed by the anterior musculature of the lower leg in order for the foot to maintain clearance above the floor. The foot then assumes a neutral position during midswing and maintains this position during deceleration until the next heel strike.

The position of the subtalar joint is also variable during gait in order to facilitate proper biomechanics of the foot and ankle. Although the subtalar joint is supinated at heel strike,[39(p144)] four to six degrees of pronation occurs immediately after heel strike to allow for shock absorption and adaptation to uneven terrain.[14(p38),40] When the foot contacts a surface, eversion occurs due to ground reaction forces on the lateral side of the foot which create a pronation moment.[41] As mentioned previously, ankle plantarflexion also occurs at this time. In addition, the tibia internally rotates while the talus plantarflexes and adducts.[7(p15),8(p392),20,39(p144)] Internal rotation of the tibia creates a flexible longitudinal arch within the foot, which assists in adaptation abilities.[12(pp258-261)]

As the subtalar joint pronates, the calcaneus everts in order to align the axes of the midtarsal joint. This movement occurs in order to "unlock" the joint and increase motion.[39(p144)] No muscle activity in the pronators occurs at that time because pronation during foot flat is a "controlled, passive movement."[7(p28)] Consequently, movement of the subtalar joint into pronation does not occur as a result of concentric muscle activity; it is merely decelerated by eccentric control of the posterior tibialis, gastrocnemius and soleus complex, and, minimally, by the anterior tibialis.

During midstance, the calcaneus begins to invert in conjunction with external rotation of the tibia, producing subtalar joint supination.[7(15)] External rotation of the tibia creates a stable longitudinal arch, adding to the stability of the foot during propulsion.[12(pp258-260)] During midstance, the tibia moves anteriorly over the talus in closed-chain dorsiflexion. The gastrocnemius, soleus, posterior tibialis, peroneal muscles, and toe flexors are active during this phase to decrease the velocity of pronation and movement of the tibia.[7(p28), 42(p80)] Following heel off, the midtarsal joint will also begin to supinate around the oblique axis, "locking" the midtarsal joint and stabilizing the foot for toe off, or propulsion.[39(p144)] As noted previously, the foot will dorsiflex for clearance above the floor and pronate slightly into a neutral position during the swing phase of gait.[42(p80)] The subtalar joint will invert or supinate again prior to heel strike.[39(p144)]

Efficient propulsion will not occur if the correct sequence of supination and pronation does not take place. In addition, the structures of the foot and ankle must be both extrinsically and intrinsically stable in order for efficient propulsion to occur. Extrinsic stability is determined by the position of the center of gravity of the body, while intrinsic stability is determined by the position of the skeleton. In addition, propulsion is produced by "an internal primary source of energy," usually the surrounding musculature.[35(p22)] Furthermore, supination is an important component of efficient propulsion. Therefore, a lack of supination, or too much pronation, may require another source of energy to make up for the deficiency.

An alternative option is to alter the biomechanical alignment of the foot with orthotics. A biomechanical problem is the most significant indication for foot orthotic prescription, rather than any specific diagnosis.[2] An example of one such biomechanical problem is abnormal or overpronation. Therefore, wearing a foot orthotic may assist in the treatment of abnormal pronation and increase the efficiency of gait.

Normal variations in the position of the foot and ankle during gait have been described. Variations in the position of the subtalar joint have also been described. However, the biomechanical alignment of the subtalar joint may be altered during abnormal pronation, which may lead to malalignment of the foot and ankle complex and differences in the function of the lower extremity.

CHAPTER III

ABNORMAL PRONATION

Abnormal pronation is known by many different terms depending on the source used. Other names in the literature include flatfoot, pes planus, pes valgoplanus, calcaneovalgus foot, pronated foot, valgus foot, and talipes calcaneovalgus.[3(p32)] For the purposes of this literature review, abnormal pronation, flatfoot, and the term overpronation will be used synonymously.

Flatfoot deformity or overpronation can be described as the presence of too much motion in the subtalar joint.[3(p32)] Flatfoot deformity has also been described as a lack of supination necessary for the rigidity of the foot during propulsion.[26(p91)] There are, however, many causes of abnormal or overpronation.

Causes of Abnormal Pronation

There are several possible etiologies of abnormal pronation, including congenital deformity or deformity acquired later in life.[3(p2)] Congenital deformities may result from genetic characteristics or from incorrect positioning of the fetus in the uterus.[3(p33)] Examples include convex pes valgus, tarsal coalition, and congenital metatarsus varus.

Abnormal pronation may also be due to an acquired deformity. Examples include traumatic flatfoot, ligament laxity, bony abnormality of the subtalar joint, and compensatory pronation due to intrinsic or extrinsic deformities. Intrinsic deformities which result in compensatory pronation at the subtalar joint may include forefoot varus, forefoot supinatus, rearfoot varus, and ankle joint equinus. Extrinsic deformities resulting in compensatory pronation include leg length discrepancies and rotational deformities of the lower leg or thigh. Rotational deformities are two of the most common extrinsic deformities.[3(pp41-55)]

Traumatic flatfoot is caused by trauma to the tibialis posterior tendon. The tibialis posterior has many important functions in the foot. First, it supinates the foot (adduction, inversion, and plantarflexion). It also provides stability to the rearfoot region in order to prevent eversion or valgus deformities in this area. Damage to this tendon puts undue stress on the ligaments and bones to keep the foot in alignment. Changes in the alignment of the foot, such as valgus positioning of the calcaneus, occur as a result of the inability of the tibialis posterior to supinate the foot. Subsequently, the foot will appear flat or overpronated.[3(p41)]

Ligament laxity is another potential cause of the flat foot deformity. If ligament laxity is present, support of the subtalar joint may not be provided by the ligaments in the area of the medial longitudinal arch (the long and short plantar ligaments, the spring ligament, and the plantar fascias). Consequently, the joint may be unable to maintain its normal position through supportive soft tissues and will be susceptible to overpronation. Also, prolonged flatfoot positioning will cause ligaments and other soft issue to become damaged, preventing proper alignment of the subtalar joint.[3(pp41-42)]

Another possible condition leading to overpronation of the subtalar joint is an abnormal formation of the bones in the joint. During the foot flat stage of gait, the body's weight is shifted medially when internal rotation of the tibia occurs. The facets between the calcaneus and talus must be aligned properly at this time to provide support to the head of the talus. In the absence of adequate support for the head of the talus, excessive plantarflexion and adduction of the talus will occur, producing overpronation.[3(p42)]

The presence of compensatory subtalar joint pronation is abnormal and may cause damage to the structures of the foot and lower extremity.[43(p195)] Compensatory subtalar joint pronation also results in the "loss of a rigid lever" provided by a stable, supinated foot in push off.[43(p195)] Intrinsic deformities that may cause compensatory pronation to occur include forefoot varus, forefoot supinatus, subtalar varus, and ankle joint equinus.[3(pp42-43)] Frequently, excessive pronation or pronation at the wrong time during the gait cycle occurs as a result of these deformities. Movement in the subtalar joint compensates for the aforementioned deformities in order to keep the foot in a solid, weightbearing position on the contact surface.

Forefoot varus is one of the most common causes of compensatory overpronation.[3(p43),25(p451),29] In this deformity, the subtalar joint remains in a neutral position; however, the forefoot is in an inverted position. Therefore, the foot does not lie flat during weightbearing, and the subtalar joint will have to evert or pronate to allow the forefoot to touch the ground completely.[29,44,45(p65)] This compensation is one of the leading causes of abnormalities in the lower leg and knee.[45(p65)] However, if the subtalar joint is unable to compensate for the forefoot varus, the forefoot will compensate by movement of the midtarsal joint or the first ray.[3(p46)]

Forefoot supinatus is similar to forefoot varus. Both deformities result in compensatory pronation at the rearfoot in the subtalar joint. However, forefoot supinatus differs from forefoot varus in regard to the tissues that are involved. The forefoot is in the same position, but forefoot supinatus deformity is due to soft tissue spasm or contracture, particularly of the anterior tibialis muscle. Forefoot varus is due to an incorrect positioning of the head and neck of the talus in the stages of development.[3(p46)]

Rearfoot varus is also a very common deformity that causes compensatory pronation of the subtalar joint. When the subtalar joint is in a neutral position, the calcaneus will be in varus and the metatarsal heads will be inverted.[25(pp453-454)] However, when the foot contacts a weightbearing surface in calcaneal varus, or inversion, subtalar joint pronation occurs to allow weightbearing on the medial side of the foot.[25(pp453-454),44,45(pp59-60)] The foot will usually return to a stable position for propulsion.[45(p60)]

Ankle joint equinus is the lack of dorsiflexion in the ankle, or talocrural, joint with the subtalar joint in neutral.[3(p47),25(p454)] In addition, the forefoot appears plantarflexed in relation to the rearfoot.[44] This is usually due to immobility of the gastrocnemius-soleus complex.[3(p47)] Thus, a person will attempt to bring the foot to the contact surface by pronating the subtalar joint.

Frequently, the body will also compensate for a leg length discrepancy (LLD) through movement at the subtalar joint. Leg length discrepancies can be structural or functional. A structural LLD is a difference in the length of the bones themselves, while a functional LLD is secondary to muscle imbalances or joint contractures which affect the position of the lower extremities. Regardless of the type of discrepancy, the subtalar joint will pronate in order to shorten the length of the limb on the side of the body with the longer limb. However, the subtalar joint on the opposite limb will supinate in order to lengthen the limb and level the pelvis and lower extremities. Overpronation on the longer side will cause stress to the joint and result in pain, especially in athletes.[3(p51-54)]

Rotational deformities in the thigh and lower leg can be the result of many factors, including soft tissue deformities, improper position of the fetus in the uterus, poor sitting or sleeping postures, genetic factors, or iatrogenic factors.[3(p49)] Each of these factors may affect the amount of pronation in the subtalar joint.

A rotational deformity of the thigh, such as excessive femoral anteversion or medial femoral torsion, results in toeing-in of the feet during gait.[3(p49)]

Prolonged periods of time in this position, especially beyond age four or five, can cause deformities to occur in other areas of the lower extremities.[3(pp50-51)] For example, the lower leg will tend to externally rotate to counteract the toe-in mechanism. Consequently, pronation of the subtalar joint occurs to compensate for this deformity.

A rotational deformity of the lower leg is called tibial torsion, and can be in an internal or external direction. Tibial torsion can be described as an alteration of the alignment of the tibia compared with the femur, giving the appearance of a twisted tibia. External tibial torsion beyond 20° is abnormal and will most likely result in compensatory pronation to keep the foot flat on the weightbearing surface.[3(pp50-51)]

The aforementioned deformities are frequently causes of abnormal pronation. Any of them may alter the anatomy and biomechanical alignment of the subtalar joint, making proper function of the foot and ankle difficult. Changes may be observed in the structure and function of the foot and ankle, especially the subtalar joint.

Changes in Structure and Function of the Foot and Ankle During Abnormal Pronation

Several clinical observations may be made regarding the appearance of the ankle and the position of the joints during overpronation. For example, the calcaneus may be in an everted or valgus position.[3(p55)] In addition, the height of the medial arch may be reduced as indicated by the results of the navicular drop test,[25(p455),46] the navicular tuberosity may be bulging medially,[(3(p55),25(p455)] or the forefoot may be abducted in relation to the rearfoot.[3(p55)] Another observation that may be made is the structure of the shoes a person wears. People with overpronation will tend to wear out the medial side of the sole of their shoes or under the area of the second metatarsal head.[25(p461),31] The heel of the shoe may also be deformed into a valgus position.[31]

Changes in the position of the ligaments, bones, and muscles which form the subtalar joint influence the function of the subtalar joint, the foot and ankle, and the lower extremity. For example, the amounts of inversion and eversion within the subtalar joint usually measure approximately eight degrees.[12(p258)] However, in persons with flatfoot deformity, both inversion and eversion may increase to 12°. These changes may be due to laxity in ligaments or other soft tissue structures, allowing increased overall range of motion within the subtalar joint.[3(pp41-42),10(p67)]

Several authors[12(p265),47-50] have studied muscle activity of the intrinsic or extrinsic foot musculature during overpronation. Studies report that the intrinsic muscles of the foot, as well as the posterior tibialis, anterior tibialis, peroneus longus, and soleus muscles become more active in the overpronated foot in order to maintain stability.[47,48]

Other changes in the alignment of the soft tissue surrounding the subtalar joint also occur. For example, with overpronation, the spring ligament may rotate laterally, producing stress on the medial capsule of the subtalar joint.[36(pp215-217)]

One change in the biomechanics of the subtalar joint involves the joint axis. During overpronation, the location of the axis changes from an oblique position to a more horizontal position.[11(pp66-67)] Rearfoot motion will likely increase with the axis in this position.[45(pp159-160)] In addition, if the axis is deviated in a medial direction, a larger pronatory moment may develop in response to ground reaction forces, increasing the potential for overpronation.[37]

Changes also occur in a person's gait pattern with the presence of overpronation. Propulsion, one of the primary functions of the foot, is significantly decreased when too much pronation occurs. As mentioned previously, pronation occurs naturally during the period between heel strike and foot flat. However, the subtalar joint may remain in pronation when it should be supinating and becoming rigid in preparation for midstance and push off. Therefore, the effectiveness of propulsion is decreased due to the lack of rigidity in the foot.[39(p145)]

There are other forms of abnormal pronation which may take place during the gait cycle.[39(p145)] For example, pronation may not occur as it should between heel strike and midstance. Instead, pronation may occur later in the gait cycle during push off. Sudden calcaneal eversion will take place between heel off and toe off, resulting in the loss of the shock absorption function and the propulsion mechanism. Also, if pronation occurs throughout the stance phase, the foot is already pronated at heel strike, leaving no room for further pronation or shock absorption. In addition, the foot continues to be pronated during push off, resulting in the loss of the rigidity of the foot for propulsion once again.

A study by Giannini et al[51] tested kinematic factors in patients with bilateral flatfoot. No significant changes were noted during the study in the sagittal plane in the hip, knee, or ankle except for a small decrease in ankle plantarflexion. However, the authors did find that the foot is typically pronated when it is in contact with the ground. The study also stated that the stiffness of the foot associated with supination occurs much later and with lesser force, resulting in a decrease in the propulsive function of the foot. Other changes reported include an overall increase in the amount of pronation, greater internal rotation of the knee, and a corresponding increase in subtalar pronation. In addition, isokinetic data showed that during plantarflexion, decreases in torque and work were produced by high velocities of movement.

There are a variety of etiologies for abnormal subtalar joint pronation. Foot orthotic prescription is one method of restoring correct alignment to the structures involved and preventing permanent damage from occurring. However, the type and severity of the deformity will determine the type of materials used in orthotic prescription.

CHAPTER IV

SELECTION OF ORTHOTIC MATERIALS

The prescription of foot orthotics for patients with abnormal subtalar joint pronation can be a difficult task. There are many options available for shapes, sizes, materials, and types of orthotics. One of the mot important components of any orthotic is the material used in its fabrication. Therefore, the decision regarding what type of material to use in fabricating an orthotic must be based on several factors, including personal experience of the clinician,[25(p457),52-54] characteristics of the patient,[4,5,54,55,58] and characteristics of the materials.*

Personal Experience of the Clinician

The personal experience of the clinician as well as the cost and availability of the materials must be taken into account when prescribing an orthotic.[53] Several qualities may be helpful in determining the type of material and the type of orthotic that will be used. The clinician must be able to accurately determine the patient's problem.[52,54,58] Without a correct diagnosis initially, the process of fabrication will be difficult and the patient may not be satisfied with the results.[52] It is also essential that the clinician be well-informed

* References 2, 4, 27, 36 (pp 196-214), 53, 54, 56 (p3), 57, 58

regarding available resources, such as the various types of materials and types of orthotics, as well as properties of those materials as they relate to specific patients, such as those with subtalar joint pronation.[45(p203),54,55(p3),58]

Finally, the personal experience of the clinician becomes important in the process of fabrication of the orthotic. Some orthotic designs, such as semirigid or rigid orthotics, require a neutral cast or model to be made of the foot in order for fabrication to be completed properly.** Physical therapists may be involved in this process in a variety of ways.[25(p457)] Following completion of the cast, the therapist can either ship the cast and the instructions to a laboratory for fabrication of the orthotic or complete the fabrication of the orthotic him/herself in an "in-house" method.[25(p457),43(pp200-201)] This decision may be based on personal preference and background of the clinician. However, if fabrication of the orthotic is completed by a physical therapist, that person must possess the skill as well as the appropriate equipment and supplies to do so.[25(p457)]

Characteristics of the Patient

Individual characteristics of patients are extremely important to consider when recommending or prescribing an orthotic. Specific factors to consider include the diagnosis of the patient,[4,5,27] the type of deformity and subsequent biomechanics of the foot,[2] the age of the patient,[4,5,58] the weight of the

---

** References 6 (p 41), 25 (p 456), 27, 36 (p 204), 43 (p 197), 45 (p 76), 59 (p 333), 60 (p 253) patient,[4,5,54] the activity level of the patient,[4,5,58] and the style of shoe the patient will be wearing.[4,5,58] The diagnosis of the patient is important because of the potential effects a disease or condition may have on bones, soft tissue, or other structures within the body. For example, a patient with a diabetic neuropathy may be susceptible to breakdown or ulceration of the skin while wearing an orthotic.[4] A softer material, such as foam, may be more appropriate in an orthotic for this patient. Also, patient with inflammatory conditions may benefit from using a more rigid material in an orthotic to increase stability of the foot and decrease inflammatory responses due to excessive movement of the joint. Furthermore, a rigid material may be contraindicated for patients with diminished shock absorption ability.[55]

The diagnosis of a patient is often related to the problem for which foot orthotics are prescribed. For example, a diagnosis of overpronation may actually be due to ligamentous laxity or a forefoot varus deformity.[3(pp41-46)] In this case, it is the underlying biomechanics of the foot rather than the diagnosis which need to be considered when prescribing the orthotic.[2] In addition, the prescription of custom-made orthotics is not recommended for an overuse injury if there is no obvious malalignment, if no symptoms associated with a malalignment are present, or if the relationship between the biomechanical abnormality and the symptoms is not clear.[31]

A biomechanical deformity which involves abnormal or overpronation may require an orthotic made of a rigid material that will control joint motion[2,27,45(p205)] or support the joint.[6(p37),59(p329)] One author also reports that soft materials may be just as beneficial in controlling biomechanical abnormalities.[61]

The age of a patient is also important to consider when prescribing orthotics. Pediatric patients require different types of orthotics than elderly patients. Difficulties may arise when the neutral cast of a child's foot necessary for fabrication of the orthotic is impossible to complete due to the child's restlessness or uncooperative behavior. Also, a foot orthotic for a child may need to be more rigid because of the larger amounts of motion available in children's joints. Conversely, an elderly patient may present with different circumstances, such as atrophy of various muscles in the legs. An orthotic for an elderly individual may need to be fabricated from very thin, lightweight materials to decrease the amount of energy required by the individual to ambulate using the orthotic.[4,58]

The weight of the patient is also an important aspect to consider when choosing material for an orthotic.[4,5,54] Added stress and strain may occur in many materials due to the extra load of a heavier patient. Therefore, overweight patients may require an orthotic made of stronger, thicker, or more dense material. These types of materials will prevent rapid compression of the material, known as "bottoming out."[4,27,62] Materials such as thick polyolefins (polypropylene and polyethylene) can be used in orthotics for heavier patients.[4]

The activity level of the patient is also an essential element to consider.[4,58] Patients who are very active in sports or other strenuous activities require a versatile orthotic. Flexibility of the material, or at least cushioning over another material, may be necessary in orthotics for active individuals to prevent irritation of the soft tissues of the foot, such as the fascia or the intrinsic musculature. In addition, flexibility is necessary for shock absorption, especially during running.[27]

An orthotic for an active individual, such as a runner, must also be rigid enough to prevent bottoming out of the material from long periods of highly intense use. As a result, materials such as polyolefins, foam, or soft orthotic for an athlete such as a runner must be both flexible and rigid in order to accommodate high forces to which the foot is subjected during running as compared to walking.[27]

Finally, the shoe style of the patient is very important to consider in the prescription of an orthotic.[4,58] The size and shape of the shoe the patient will be wearing will help determine the type of material needed and the shape the material will need to take. For example, women's high-heeled shoes lack extra space inside them. Use of an orthotic in a woman's shoe may result in extra bulk which could force the foot out of the shoe or cause compression of the forefoot.[4] Therefore, thin materials such as carbon graphite, fiberglass, and composites have been used to fabricate orthotics for women's dress shoes. However, patients who must have a larger or thicker orthotic to treat a particular problem may consider wearing an in individualized shoe or a shoe with extra depth to allow adequate space for both the foot and the orthotic.[27,30]

Characteristics of Materials

Through the use of advanced technology, there are many new types of materials being designed and produced.[53] Therefore, background knowledge of these materials and their characteristics is essential for the prescription of foot orthotics.[54,56(p3)] Factors that must be considered include the purpose or goal of the orthotic, the materials which are available, and the properties of the materials.

Goals of Orthotics

In order to decide what type of material to use in the fabrication of an orthotic, a clinician must first determine the purpose or goal of the orthotic.[63(p236)] There are numerous goals of treatment for abnormal subtalar joint pronation using orthotics mentioned in the literature. (Table 1)

Materials

The decision of what material to choose when prescribing an orthotic is very important. The literature discusses several of the materials that are currently available for use in the prescription of foot orthotics. Examples of orthotic or shoe insert materials include plastic materials, foam, rubber, composites, cork, leather, and felt.*** These materials can be used in a variety of ways in the fabrication of orthotics; however, it is not recommended to state specific tasks for which a certain material should be used. This limits the

---

*** References 4, 6, 21, 36 (p 213), 53, 54, 56 (pp 22-23), 58, 65, 66

Table 1.—Goals of Orthotic Treatment
• shock absorption and cushioning of the foot[2,27,59(p329)]
• support of structures of the foot and ankle[25(p456),27,36(p38),52,59(p329),64]
• alteration of biomechanical alignment or position of the foot and lower extremity[2,52,59(p329),60(p250),65(p443)]
• control of joint motion, especially pronation[1,2,27,36(p38),45(p205)]
• even distribution and relief of pressure[27,59(p329)]
• reduction of pain[52]
• prevention of deformity[36(p38),52,63]
• protection of a weak or painful part[36(p38),63]
• improvement of joint function[26(p95),52,63]

potential uses a material may have beyond a specific task.[54] Therefore, the materials used in the fabrication of orthotics will be discussed in a general manner, including mention of possible uses where appropriate.

Plastic Materials

Plastic materials make up one of the largest groups of materials. Common characteristics of plastics when used in the fabrication of orthotics include being lightweight, easily shaped and fabricated, chemically resistant, and cosmetically appealing.[36(p212)] There are several types of plastics, including thermoplastic materials and thermosetting materials.[4,54,56(p23),58]

Thermoplastic Materials

Thermoplastics have been a very common material with which to fabricate orthotics since the 1950s; however, they were developed at least 120 years ago.[4,58] Thermoplastics can be very useful in the fabrication of orthotics because they can be molded to a certain shape when the temperature of the material is increased. They will also become rigid once the temperature is lowered.[4,54,56(p23),58] Thermoplastics are made up of polymers, or substances that are "formed by a combination of two or more molecules of the same substance."[67(p1554)] The polymers in thermoplastic materials are in a linear formation, which is the quality that allows them to be reshaped with the application of heat.[4,58]

Polyolefins.—One category of thermoplastics used widely in the fabrication of orthotics is the polyolefin materials, which include polypropylene and polyethylene.[4,58] These materials are recognized as being very stable and having very low rates of breakage when used in the fabrication of orthotics.[4,56(p23),58] They are also resistant to the absorption of water and other solvents, which is beneficial for cleaning.[30(p75),56(p23)] Of the two materials, polypropylene is denser, is better able to retain its shape than polyethylene, and does not bottom out as quickly as polyethylene.[4,56(p23),58] In addition, polypropylene, as compared to metals, is not as strong but is more flexible.[36(p203)] Therefore, polypropylene orthotic devices have been quite popular due to the ease of fabrication and shaping, cosmetic appeal, and precise fit.[36(p204),56(p23)] However, the overall capacity for maintaining shape is lacking in both of these materials.[4,58]

A specific example of a thermoplastic material using a polyolefin is low-density polyethylene sheet.[53,54] Polyethylene sheet is made by compressing ethylene and can be molded when heated to an approximate temperature of 125°C. Rome[53,54] states that this material has a "high resilience to compression," and is considered very tough, lightweight, and somewhat flexible. Polyethylene sheet is also resistant to water absorption.

Acrylics.—Another category of thermoplastics is the acrylics.[4] Acrylics are typically translucent and quite "stable to outdoor weathering."[4(p54)] Acrylics are made up of methacrylate and are known for their ability to be shaped with the application of heat, as all thermoplastics are; furthermore, they are recognized for their great strength.[4,54] One example of an acrylic is polymethyl methacrylate. Rome[54] describes polymethyl methacrylate as "the most rigid material commonly used in chiropody."[54] This material is also known for its high density, toughness, and rigidity.[53,54] Polymethyl methacrylate may be effective in stabilization of the foot; however, it is not particularly useful for the fabrication of foot orthotics, especially shock absorption and cushioning of the foot.[53]

Thermosetting Materials

The second type of plastic material used in the fabrication of orthotics is thermosetting plastics.[58] These materials are made up of a network of molecules which are chemically bonded in a three-dimensional pattern throughout the material rather than in linear formation like the thermoplastic materials.[4,56(p22),58] Thermosetting materials require the application of heat to harden the material initially; however, any further heating does not soften the material and will result in breakdown of the material.[56(p22)] Thermosetting plastics cannot be reshaped following formation as the thermoplastic materials can. However, custom-made orthotics can be fabricated for a patient with this material if necessary by placing it over a mold.

Foam

Another category of materials is the foam materials which have been used in the fabrication of orthotics since the 1940s.[4] Materials in this category can be described as open-cell or closed-cell foams. Open-cell foams are made up of many pockets of air which communicate with each other. For this reason, they have been advocated for use when heat dissipation and evaporation are needed.

Conversely, closed-cell foams still contain pockets of air, but they do not connect with each other. Consequently, closed-cell foam materials are more useful for insulation of heat.[4] An example of a closed-cell foam material that is commonly used in orthotic fabrication is plastizote, which is a lightweight material made up of polyethylene and nitrogen gas.[4,54] These components are cross-linked through chemical bonds or high energy electrons.[53] Also, since polyethylene is a thermoplastic material, this component allows closed-cell foam to be shaped with the application of heat.[54] This material is also known for its strength, toughness, and variable densities which can be used for many applications.[4,53,54] Cross-linked closed-cell polyethylene foam may be beneficial in absorbing shock; however, it compresses rapidly, resulting in bottoming out.[53,54]

An example of an open-cell foam material is open-cell polyurethane foam which is highly suitable for fabrication of orthotics because of its ability to cushion the foot and absorb shock.[53] This material is also excellent for prevention of skin breakdown.[54] Open-cell polyurethane foam is considered a thermosetting material and can be valuable in the fabrication of orthotics.[4,53] As Rome[53] states, "A material that compresses or deforms slowly over a period of time would be the ideal material to accommodate the various forces found within the foot-ground interface." Open-cell polyurethane foam can be considered such a material. Polyurethane may also be manufactured in a closed-cell form.[4]

In one study comparing various materials, Lewis and colleagues[57] assessed the function of several well-known materials compared to new materials with potential use in the fabrication of orthotics. To measure the function of these materials, the authors tested the performance index (PI) of each material which considers the service life of the insert, environmental conditions such as temperature, and several properties of materials, including hardness, density, and modules of elasticity. The author found that the performance index of a material decreased as the thickness of the material increased. Furthermore, the materials with the highest performance index were the urethane foams.

Rubber

Another category of materials used in the fabrication of orthotics is the rubber materials. The composition of these materials is similar to that of the foam materials and can also be classified as open-cell or closed-cell. Closed-cell rubber, for instance, is made up of rubber which contains pockets that do not interconnect throughout the material. In contrast to foam materials, these pockets are not filled with air; they are filled with nonflammable nitrogen gas. Closed-cell rubber compresses with the application of a force; however, it is able to retain 70% of its thickness and will return to its original form following removal of the pressure. This material may be useful in shock absorption depending on the density and thickness of the material.[53,54]

Another type of rubber is open-cell rubber. Open-cell rubber is very similar in make-up to the open-cell foam materials. This rubber material contains air-filled pockets that connect with each other. Open-cell rubber is not recommended for shock absorption in orthotics because the material will collapse with the application of a force. The material will return to its original form initially, but with repetition, open-cell rubber is able to retain approximately 50% of its thickness.[54]

Composites

Composites are another type of material used in the fabrication of orthotics.[58] Composites are made up of a combination of materials which usually include a type of thermosetting resin interlaced with carbon, graphite, or fiber glass.[4,58] These materials are very thin, lightweight, and stronger than either of the separate materials. In addition, composite materials possess fatigue resistance, are "resistant to breakage," and show "excellent shape retention."[58] However, composites cannot be changed once they are built due to the properties of the thermosetting resin.[4,58] Olson[58] suggested making a composite material using a thermoplastic resin rather than a thermosetting resin to enable shaping the orthotic with the application of heat.

In one study by Richie and Olson,[21] a comparison of two materials used in the fabrication of orthotics for sports injuries, polypropylene and a composite named TL-2100 SF, was performed. The composite material was composed of a semiflexible acrylic thermoplastic material and fortified with graphite. Categories tested in the study include the fit in shoe, weight, resilience and springiness, support and control, symptomatic relief, and overall comfort. The authors found that TL-2100 SF, the composite, was considered "lighter, more resilient, and more comfortable than the polypropylene material" by the subjects. However, there was no significant difference in the overall effectiveness of the two materials, as 70% of the responses in the study were either good or excellent in all categories for both materials.

Other Materials

Cork is another material used in the fabrication of orthotics.[4,53] Various cork materials can be molded with the application of heat and are used to fabricate orthotics after the completion of a neutral cast.[4] The cork materials that cannot be shaped with heat are generally used for filler material for the forefoot or arch. Additionally, some types of cork can be used as arch supports.[66]

Leather is another material that may be considered for use in the fabrication of orthotics.[53,58] It is one of the older materials used for the purpose of orthotic fabrication.[58] However, leather can also be used in an arch support.[6(p37),66] Leather is considered a fairly soft material and may not be very durable.[58]

Finally, felt is a material that has been noted in the literature for use in foot orthotic fabrication. However, felt is generally used as a covering for other materials.[65(p443)]

The selection of a material is dependent on the needs of the patient. This is an important decision that the clinician who is prescribing or fabricating an orthotic must make accurately. In addition to knowledge regarding what materials are available, the clinician must also be aware of the properties of those materials.

Properties of Materials

Numerous properties of materials are discussed in the literature, many of which are interrelated but slightly different from each other. However, minimal data exist concerning specific properties of materials and reasons for use in orthotic fabrication.[54]

There are two basic requirements of materials used in the fabrication of orthotics.[54] First, the materials "should not deform in service beyond limits prescribed by functional or aesthetic requirements." Second, "they should not fail, rupture, or deform within their scheduled lifetime."

In addition, many of the properties described in the literature can be derived from the key ideas of stress and strain.[36(pp196-197),53] Stress can be described as a force per unit that is applied to an object.[4,53] Different types of stress include tensile, shear, and compressive stress.[36(p197),53] Conversely, strain can be described as the amount of change or deformation that occurs in a linear direction within the material in response to a stress.[4,36(p197),53]

Compressibility is an important concept to consider in the decision of what material to use in the fabrication of orthotics.[4] If stress is applied to a material, it will compress.[53] The amount that the material deforms during the compression is the compressional strain.[53,54]

Materials can also be described according to compressive strength. Compression can be defined as a "state of being pressed together,"[67(p430)] while strength is "the ability to withstand load."[36(p196)] Compressive strength is a combination of these ideas and can be described as the greatest amount of stress that can be applied to a material during a test.[53] In addition, the material may or may not reach its breaking point during the compression testing.

Ductility can be described as the ability of a material to deform and compress before a fracture occurs.[36(p196)] A material with a high amount of ductility is superior for use in the fabrication of orthotics.[36(p213)] Another related concept is toughness which can be described as "the ability of a material to withstand shock loading without failure."[36(p196)] Fatigue resistance, which is also similar in meaning to ductility and toughness, is the "ability to withstand cyclic loading." Fatigue resistance may be a desirable property for a material used in meaning to ductility and toughness, is the "ability to withstand cyclic loading." Fatigue resistance may be a desirable property for a material used in foot orthotics in order to facilitate a long period of use for the orthotic. Essentially, materials which allow some compression to occur, but do not totally collapse, are the most desirable for use in the fabrication of orthotics.[54,68]

When a force is applied to a material, the material will compress, as noted above. However, when the load is maintained for a period of time, creep may occur. Creep is referred to as "a gradual increase in deformation."[4] In addition, creep occurs in response to a constant stress.[53]

In addition to creep, the resilience or elasticity of a material must be taken into consideration.[4,36(p196),53] Resilience and elasticity are similar in meaning and refer to the ability of a material to return to a normal shape after loading.**** A measure of this property is recovery, which refers to the "extent to which a material returns to its original size and shape after a deforming force is removed."[4] In addition, recovery is based on a measure of time following the removal of the force.[53] Terms such as compression set and set both refer to the amount of deformation in a material that is still present following this recovery time.[4,53]

Density is another important property to consider when choosing a material to use in an orthotic. Density can be defined as the "mass per unit volume of material."[53] It provides a measure of the relative weight of a material.[36(p196)] A related concept is hardness, which is a combination of several properties, including density.[56,67(p846)] Materials which are very dense or hard are

---

**** References 4, 36 (pp 196, 200), 67 (pp 611,1699) not recommended for use in orthotics for shock absorption.[53,54] A material with low density is not desirable either; therefore, a material with a moderate level of density is the most appropriate for an orthotic.[53]

The energy return ability (ERA) of a material is also important to consider in the prescription and fabrication of orthotics. This property can be described as the "energy that is not dissipated by the insert material" but is returned to the person.[57] Materials with a high ERA are helpful in preventing fatigue in the feet of the person wearing the device. In addition, materials which are able to store some energy in the form of strain energy are beneficial for shock absorption.[54] If strain energy is not preserved within the material, a great deal of energy is lost as heat or kinetic energy.[53]

Finally, a material used in the fabrication of an orthotic should be very durable. Durability is described as the "ability to withstand changes."[54] This relates back to one of the original requirements of a material for use in orthotics: the material should not fail while it is used as an orthotic.[54] An orthotic, and consequently, a material, which is not durable and needs to be replaced often is very costly and time-consuming for the clinician.[53] Therefore, all of the aforementioned properties must be considered carefully when deciding what material to use in an orthotic.

The selection of a material for use in the fabrication of an orthotic is a complicated process. The personal experience of the clinician, individual characteristics of the patient, and the characteristics of the materials must be taken into consideration in order to provide an effective orthotic with the best results possible for the patient. Another aspect included in the prescription of an orthotic is the decision regarding what type of orthotic will be fabricated with the chosen material. In addition, the clinician must determine if any additional posts are necessary.

CHAPTER V

METHODS OF ORTHOTIC MATERIAL APPLICATION

Orthotics can be fabricated using a variety of materials with extremely diverse properties, as mentioned previously. Orthotics can be used individually to accomplish a treatment objective. However, additions to the orthotic may be necessary to suit an individual foot. Therefore, several types of orthotics and methods of applying posts to the orthotics will be discussed.

Types of Orthotics

There are several ways to classify orthotics and the types of materials used to fabricate them. Three basic categories of orthotics are described in the literature, including 1) soft or flexible, 2) semirigid or semiflexible, and 3) rigid.[2,25(p456),27,60(p252),65(p443)] However, McPoil and Cornwall[69] state that "differences of opinion exist among authors as to whether rigid or soft orthoses should be prescribed." Each type of orthotic may also be classified as accommodative or functional. An accommodative orthotic is generally used to maintain a rigid or unmoveable foot, while a functional orthotic is used "to control a more flexible foot by providing support, stability, or both."[27]

Soft orthotics are typically considered accommodative orthotics and can be useful in a variety of ways. Soft orthotics may be used to accommodate a rigid deformity such as pes cavus foot.[6(p24)] In addition, orthotics made with soft materials are used to distribute pressure rather than control joint motion.[45(p205)] A soft orthotic may also be used as a temporary device prior to fabrication of a permanent semirigid or rigid orthotic in order to determine whether orthotics would be successful in treating a particular problem.[65(pp443-444)] Furthermore, a soft orthotic may be used to treat patients with mild overuse syndromes.[25(p456)]

Soft orthotics are fabricated with pliable or flexible materials such as felt,[65] cork,[2,66(p277)] leather,[2] rubber,[66(p278)] and cross-linked polyethylene or other foams.[2,27,66(p277)] However, rubber is the least desirable of these materials because it compresses and deforms easily.[66(p278)] Soft materials such as these are used in various ways. For example, a material such as felt may be used as a covering for a harder orthotic.[65(p443)] Also, soft materials can be shaped into pads for use in narrow shoes, particularly when larger or more rigid materials do not fit inside the shoe.[25(p456)]

Soft orthotics are beneficial for many reasons. An advantage of soft orthotics is that they can be easily adjusted in response to changes in the patient or to achieve proper fit.[2,65] However a major disadvantage of soft orthotics is that the materials used in them tend to lose thickness and bottom out quickly.[27] As a result, the orthotic has a very short lifespan and may require frequent replacements.[2]

Semirigid or semiflexible orthotics are another category of orthotics discussed in the literature. Semirigid orthotics are more functional but less accommodative than soft orthotics.[27] Some types of semirigid orthotics require a neutral cast of the patient's foot for fabrication.[25(p456),45(p205),65] Consequently, semirigid orthotics are considered more permanent than soft orthotics.[65]

Semirigid orthotics provide both control of motion in the foot and cushioning for shock absorption and comfort.[2] Therefore, semirigid orthotics are often a good choice for athletes, especially those with symptoms of increased severity compared to those who use the soft orthotics.[2,25(p456),65] Runners are one of the most common athletes to receive semirigid orthotics.[65(p444)] Athletes whose sports involve a lot of lateral movements, speed, or jumping also tolerate semirigid orthotics quite well.[25(p456),65(p444)] Another advantage of semirigid orthotics is that they do not bottom out as quickly as soft orthotics.[27]

Various types of materials are used in the fabrication of semirigid foot orthotics. Plastic materials such as thermoplastics are frequently used because they can be molded with the application of heat.[2,25(p456),27] Polypropylene and polyethylene have been named as examples of thermoplastic materials in the literature.[4,56(p23)] Other materials used in orthotics and inserts include rubber, leather, cork, and various combinations of materials.*

Another category of orthotics described in the literature is rigid orthotics. Rigid orthotics are also known as functional orthotics.[25(p456),27,43(p204)] They are specifically designed to provide control of motion and biomechanical function in

---

* References 25 (p 456), 27, 65 (p 443), 66 (p 277)

the joint.[2,65] Many rigid orthotics, as well as semirigid orthotics, require neutral casting of the foot in a nonweightbearing position in order to complete fabrication.[25(p456),45(p205),65] Consequently, rigid orthotics are also more permanent than soft orthotics.[65(p444)] In addition, some athletes such as long-distance runners used rigid orthotics for the extra control they provide.

Rigid orthotics are fabricated using a variety of materials. Examples of materials include acrylics,[27,65(443)] various types of plastic,[25(p456)] thermoplastic polymers,[27] graphite,[2] fiberglass,[2] or steel.[2] Many of these materials can be shaped at extremely high temperatures.[27]

There are several important advantages of rigid orthotics. Rigid orthotics are very "durable" and "supportive," even more than semirigid or soft orthotics.[27] As mentioned previously, they provide very precise control of motion in the joint. However, a disadvantage of rigid orthotics is that they "must be fabricated according to precise standards with little room for error."[2] Due to these circumstances, rigid orthotics have the greatest risk for complications if they are not fabricated properly.[2,45(p205)]

Several studies have been performed to evaluate the efficacy of soft, semirigid, and rigid orthotics. In one study performed by Brodsky et al,[27,62] the function of the three types of orthotics was assessed. The study indicated that the soft materials, such as polyethylene foams, had good pressure distribution. However, when subjected to repeated stress, the foam bottomed out more quickly than other types of orthotics. Consequently, it was suggested by

Janisse[27] that an ideal orthotic should be fabricated using a combination of several materials.

The effects of soft versus rigid orthotics have also been studied.[61,69] These studies have shown that soft orthotics may be considered before rigid orthotics in some situations. Soft orthotics may be useful in reducing the amounts of vertical force acting on the foot and the lower extremity.[69] Soft orthotics may also be useful in correcting biomechanical abnormalities or providing temporary symptom relief due to an athletic injury.[61] However, another source in the literature reported that orthotics made of semirigid or rigid materials are the most useful in "controlling abnormal movement."[45(p205)]

Posting Methods

In the fabrication of an orthotic, extra material may need to be added to the orthotic in certain areas to accomplish the treatment goal. For example, when fabrication of an orthotic for a person with abnormal subtalar joint pronation is completed, an additional force may be required beyond the original orthotic to maintain the joint in the proper position. The extra material in certain places provides the additional force needed to place the foot in a functional position and is called a post.[6(p41),59(p335)]

As previously mentioned, the axis of the subtalar joint moves from its original position to a more horizontal position during abnormal subtalar joint

---

** References 31, 40, 43 (p 194), 59 (p 335), 70 pronation.[11(pp66-67)] For this reason, the force must be positioned to influence the location of the axis and return it to the proper position.[36(p225)] Posts can be located on the medial or lateral side of the foot[43(p194)]; however, posting to correct abnormal subtalar joint pronation should take place on the medial side of the foot.** Posts can also be used to "support or control movement" in a joint.[43(p194)] However, if orthotics or posting material are used, the muscles which surround the joint should not be limited in activity by too much support in the orthotic.[70]

Posting is used in conjunction with biomechanical or functional orthotics, which are used to control excessive movement in the subtalar joint.[43(p193)] There are two types of posting methods used with biomechanical orthotics, including rearfoot posting and forefoot posting.[43(p194),45(pp203-212)] In addition, posts can be described as intrinsic or extrinsic. Intrinsic posting is completed by changing the shape of the original cast of the patient's foot prior to fabrication of the orthotic.[45(p203)] This technique makes the addition of extra material unnecessary. Conversely, extrinsic posting is completed by making additions to the orthotic shell after fabrication of the orthotic. Extrinsic posting may be more bulky within the shoe than the intrinsic posting method; however, it may be more easily modified for a better fit.[45(p208)]

The purpose of a rearfoot post is to improve the position of the subtalar joint by controlling calcaneal eversion and decreasing internal rotation of the tibia.[43(p194),71] The size of rearfoot post that works well inside most shoes is between five and six degrees.[43(p196)] In addition, extrinsic rearfoot posting is the most common method of controlling movement in the subtalar joint.[45(p209)]

There are various types of rearfoot posts discussed in the literature. Extrinsic rearfoot posts may be used to limit excessive or abnormal pronation occurring at the subtalar joint and to permit some motion for shock absorption.[40] For example, a standard rearfoot post controls motion at the subtalar joint while incorporating four degrees of motion into the post to allow for shock absorption. The standard rearfoot post extends across the entire heel.

Many rearfoot posts for abnormal subtalar joint pronation are variations of the standard post. For example, the short post is not as long as the standard post and does not incorporate any motion. Less control of motion is available with the short post compared with the standard post due to the decrease in the amount of material placed medial to the joint xis. However, the short post is less bulky.[40]

Conversely, the medial post extension has extra material placed medially that continues one centimeter beyond the length of the standard post. The addition of extra material allows more control of pronation.[40]

Another extrinsic rearfoot post only covers the medial side of the foot, but still controls the amount of subtalar joint pronation. This posting method is especially effective for patients who land either at the midpoint of the heel or in an everted position upon heel strike.[40]

The second type of posting method used with biomechanical orthotics is the forefoot post. Forefoot posts are generally used when an abnormality of the foot is present, such as forefoot or rearfoot varus deformities.[43(p195),45(p62),60(p250)] Therefore, the purpose of a forefoot post is to support the foot medially and bring the 'floor to the foot'[59(p335)] to allow weightbearing on the ground.[6(pp24,41),43(p194),45(p63),60(p250)] By supporting the foot in its existing position, compensation such as subtalar joint pronation will be unnecessary.[43(p195),45(p76)]

Complete correction of a forefoot deformity may not be essential to provide relief.[43(p196)] For example, an average forefoot post is reported to correct approximately 62% of a forefoot varus abnormality. In addition, if the amount of forefoot varus is measured at less than six degrees, a forefoot post will correct approximately 90% to 100%0 of the deformity. Forefoot posts between six and eight degrees usually fit well inside most shoes.

Several studies have been performed to determine the effects of the aforementioned posts, with conflicting results. Some authors report better control of abnormal subtalar joint pronation without a post,[40] while others report success with various methods of posting.[28,29.40] One author reports that the most important influence of a rearfoot post is in decreasing the velocity of eversion rather than controlling it.[28] Another author reports success in controlling abnormal subtalar joint pronation using either a combination of forefoot and rearfoot posts or rearfoot posts alone; however, forefoot posting alone was less effective.[29] In addition, Blake and coworker[40] found that the amount of pronation was reduced with the use of an extrinsic rearfoot post but was not prevented.

There are many factors that must be considered when fabricating an orthotic for abnormal subtalar joint pronation. The clinician must determine the appropriate type of orthotic to use, such as soft, semirigid, or rigid orthotics. In addition, the clinician must determine whether a post is needed to ensure proper positioning of the foot inside the orthotic. Due to the variability in the methods of fabricating orthotics, the effectiveness of orthotics is rather controversial.

CHAPTER VI

EFFECTIVENESS OF FOOT ORTHOTICS

Research shows varied results for the effectiveness of foot orthotics in treating abnormal subtalar joint pronation. It has not been proven that the use of orthotics can change a flatfoot deformity[43(p194)]; however, orthotics may be helpful in the control of motion or biomechanical realignment of the bones and soft tissue that make up the subtalar joint.[36(p38),59(p329),72] In addition, the opinion of the patients using the orthotics has been a primary indicator of the level of success achieved with a foot orthotic.[43(p193),73] The biomechanical effects of orthotics have also been studied; however, research has not been performed as extensively in this area.

Information concerning patient satisfaction is typically gathered using questionnaires which address the main concerns of the patients. Surveys may examine the degree of satisfaction using the orthotic, the amount of pain relief, the need for an adjustment period, whether the orthotics continue to be used up to two years following prescription of the orthotic, or the patient's ability to return to previous activities.[52,74] Many studies concerning patient satisfaction with orthotics report favorable results.[52,74,75]

Seventy-six percent of the subjects in one study reported a complete resolution of symptoms or at least some improvement in symptoms using orthotics, with approximately 90% of the subjects continuing to use the orthotics after the symptoms were resolved.[75] Another study reported that 83.1% of the subjects were satisfied with the orthotics, with 95.3% of the problems either totally or partially resolved.[52] In addition, a study by Donatelli et al[74] showed that 91% of the subjects were either very satisfied or satisfied with the orthotics and that orthotics were able to relieve pain in 96% of the subjects. Furthermore, 70% of the subjects in a study by Blake and Denton[76] reported that using orthotics "definitely helped."

In addition to the level of patient satisfaction, there are several other variables used in the literature to determine the effectiveness of foot orthotics. Monitoring alterations in structure or function of the lower leg or foot with and without orthotics is one method of determining the effectiveness of foot orthotics. There are several variables mentioned in the literature that may be tested (Table 2). The results of studies using these testing variables show that the effectiveness of foot orthotics is variable. Often, the accuracy of the initial effectiveness of foot orthotics is variable. Often, the accuracy of the initial examination and diagnosis and the type of orthotic prescribed will affect the level of success achieved with the orthotic.[54,58] Variation in the results may also be due to differences in the materials, methods of posting, testing conditions,

Table 2.—Biomechanical Variables Tested to Determine the Effectiveness of Orthotics for Abnormal Subtalar Joint Pronation
calcaneal eversion[1,32,77,78]
amount of pronation at the subtalar joint[33,78,80]
velocity of pronation[32,78,79,81]
time required to reach full pronation at the subtalar joint[78]
time spent in pronation of the subtalar joint[81]
muscle activity in the lower leg or foot[47-50]
internal rotation of the tibia[55,77,82]

velocity of the subjects' walking or running, or the type of footwear worn by subjects.[1,33,82-84]

Calcaneal eversion is a normal part of the pronation movement in the subtalar joint.[31,34] During abnormal or overpronation, however, the amount of calcaneal eversion may be in excess of what is required. Additionally, control of motion of the calcaneus may be the key to controlling abnormal pronation.[85] Therefore, comparisons of the amount of calcaneal eversion with and without orthotic use may be valuable in determining the effects of orthotic treatment for overpronation. Studies have been performed that evaluate this variable during various sequences of standing, walking, or running.[1,32,77-79]

One study by Brown and colleagues[78] showed no significant difference in the amount of calcaneal eversion using shoes, arch supports, or biomechanical orthotics during walking. However, another study by Taunton et al[77] reported "a significant decrease in the amount of eversion during the support phase of running" using corrective running orthotic devices. Several other authors have also shown a reduction in calcaneal eversion using orthotics.[1,32,79]

As mentioned previously, pronation occurring in an excessive amount is abnormal and may be treated with orthotics.[20,27] Therefore, the total amount of pronation occurring at the subtalar joint may be an important variable to evaluate in order to determine the effectiveness of orthotics for abnormal or overpronation. One study reported a decrease in the amount of subtalar joint motion using soft foot orthotics.[80] Another study also reported a significant decrease in the maximum amount of pronation using shoes specially designed to test rearfoot motion.[33] However, Brown and colleagues[78] reported no significant change in this variable.

Velocity of pronation occurring at the subtalar joint may be another important variable used to determine the effectiveness of orthotics for overpronation. One author reported that the velocity of movement into pronation or eversion may be as important to consider as the amount of pronation.[28] One study by Smith and colleagues[32] reports a significant decrease in the velocity of calcaneal eversion. The same study also states that the velocity of calcaneal eversion will increase if the speed of running is increased. Several other studies also report a significant decrease in the velocity of pronation or calcaneal eversion using orthotics.[78,79] However, one study reported no significant difference in the velocity of pronation.[81]

Other factors that should be evaluated when determining the effectiveness of foot orthotics for overpronation are the time required to reach full pronation or "time-to-maximum pronation" in the stance phase of gait and the amount of time spent in that position.[78,81] As mentioned previously, an objective of orthotic treatment is to decrease the velocity of pronation; therefore, the time-to-maximum-pronation should increase if an orthotic is to be successful. Also, the function of the foot as a rigid lever for propulsion is lost if the foot remains in pronation too often; therefore, another goal of orthotic treatment is to reduce the amount of time the foot spends in pronation.

One study found an increase in the time-to-maximum-pronation using biomechanical orthotics.[78] Additionally, a study by Rodgers and colleagues[81] reported a decrease in the time spent in pronation in the support phase of gait using a foot orthotic.[81] However, both of these studies suggested that caution be used when drawing conclusions concerning the use of foot orthotics based on the results of their research. Therefore, these variables are not verified as indicators of success with orthotics for overpronation.

A strong, normal arch needs very little support by the surrounding musculature to maintain its position; most of the support is provided through the position of the bones of the foot and the integrity of the ligaments.[49] However, during abnormal or overpronation, additional support for either the medial longitudinal arch or the subtalar joint may be necessary to provide a functional position of the foot. As mentioned previously, support and stability may be provided by the surrounding musculature.[48] Therefore, the effectiveness of foot orthotics for overpronation can also be determined by assessing the activity of certain muscles with and without the use of orthotics. Various muscles of the lower leg and foot have been tested for this purpose.

Early studies of patents with flat feet report increased muscle activity in several muscles to increase the stability of the foot during propulsion, including the intrinsic muscles of the foot and extrinsic muscles such as the anterior tibialis, posterior tibialis, peroneus longus, and soleus muscles.[47,48] Another early study reported that muscle activity in normal subjects increased only when muscles surrounding the medial longitudinal arch were stressed using loads in excess of 400 pounds.[49] Various intrinsic and extrinsic muscles were tested in this study, including the anterior tibialis, posterior tibialis, peroneus longus, flexor hallucis longus, abductor hallucis, and the flexor digitorum brevis.

A more recent study evaluated the muscle activity of the anterior tibialis, peroneus longus, and the gastrocnemius muscles using orthotics.[50] In contrast to the authors' hypothesis, no significant differences in average electromyographic (EMG) activity were found when comparing the anterior tibialis and the gastrocnemius muscles. However, muscle activity in the anterior tibialis did increase significantly after heel strike with the use of an orthotic compared to without the orthotic. No data were reported concerning the EMG activity of the peroneus longus due to inaccurate readings. The author suggested further research to determine the muscle activity of the posterior tibialis and peroneus longus muscles using orthotics.

As noted previously, the amount of internal tibial rotation and the amount of pronation in the subtalar joint are related. Therefore, the effectiveness of foot orthotics can be determined by measuring the amount of tibial rotation occurring with the use of orthotics. If the orthotic is effective, the amount of pronation should decrease, leading to a subsequent decrease in internal tibial rotation. This method for measurement of rearfoot motion and tibial rotation has been reported to be quite reliable.[55]

One study reported no significant change in the amount of internal rotation of the tibia using corrective running orthotic devices.[77] However, one study reported a significant decrease in internal rotation of the tibia using an orthotic.[82] The same author suggested that the greatest effect of the orthotics was during the first 50% of the stance phase. Another study reported similar results of a significant decrease in internal rotation of the tibia using accommodative orthotics.[55]

There are also methods of predicting the success of orthotics for overpronation. The type of axis of the subtalar joint has been suggested as an indicator of the success of orthotics. For example, a subtalar joint axis which is low or close to the transverse plane, as in abnormal or overpronation, can often be treated effectively with foot orthotics.[45(p160),86]

An orthotic must also have certain qualities in order to be effective. First, the orthotic should accomplish the treatment objective and be composed of quality material. In addition, the orthotic should be lightweight, reliable, adjustable, cosmetic, hygienic, safe, and acceptable to the patient. Furthermore, the orthotic chosen by the clinician should be provided or replaced quickly and efficiently.[33(pp73-75)]

The effectiveness of treatment with orthotics for abnormal or overpronation is variable. However, several studies report positive responses from patients who use orthotics. In addition, some of the aforementioned studies report the success of orthotics. Therefore, treatment for overpronation with orthotics may be beneficial and should be considered an option for treatment for patients with abnormal subtalar joint pronation.

CHAPTER VII

CONCLUSION

Abnormal subtalar joint pronation, also known as overpronation, is a problem that may cause changes in the structure and function of the foot. Foot orthotics are one treatment option for this problem. An appropriate orthotic must be prescribed depending on factors such as the anatomy and biomechanics of the foot and ankle, the personal experience of the clinician, characteristics of the patient, and characteristics of the material.

An important part of the prescription process is the selection of the material. There are a variety of materials available for use in the prescription and fabrication of orthotics and inserts, including plastic, foam, rubber, composites, cork, leather, and felt.* According to the literature, materials which are the most beneficial for abnormal subtalar joint pronation include thermosetting plastic materials, especially polypropylene; open-cell polyurethane foam; closed-cell polyethylene foam; and rubber or composites depending on the purpose of the orthotic.[4,21,53,54,57,58] Materials which may not be useful for the fabrication of orthotics are the acrylic materials.[53]

---

* References 4, 6 (p37), 21, 36 (pp212-213), 53, 54, 56, 58, 66

A material for an orthotic must also have certain properties to be successful. Properties which can be useful in the fabrication of foot orthotics include a high ductility, an ability for compression but a low compressibility and high compressive strength, high resilience or elasticity, and a medium density.[4,36(p213),53,54,57,68] However, materials which possess properties such as extremely high or low density or a large capacity for compression may not be beneficial for orthotics for abnormal subtalar joint pronation.[53,54]

Several types of orthotics can be fabricated using one or more of the available materials. The three basic types include soft or flexible, semirigid or semiflexible, and rigid.** Soft orthotics are useful for shock absorption for rigid deformities,[6(p24)] while semirigid orthotics are beneficial for athletic use.[2,25(p456)] Finally, rigid orthotics are useful if control of excessive motion is necessary.[2,45(p205)]

In addition to the type of orthotic, the clinician must also determine whether posting is necessary.[6(p41),31,59(p335)] Posting is used for abnormal subtalar joint pronation on the medial side of the foot, using either a rearfoot post, forefoot post, or both.[31,40,43(p194),59(p335)] Rearfoot posts control motion in the calcaneus and tibia, especially eversion and internal rotation, respectively.[43(p194),71] However, forefoot posts are used to support a deformity and allow for full weightbearing on the foot.[59(p335),60(p250)] The literature reports

---

** References 2, 25 (p 456), 27, 60 (p 252), 65 (p 443) conflicting results concerning the efficacy of posting; however, some studies have reported success using posting.[28,29,40]

Overall, the effectiveness of orthotics is still quite controversial. Several studies have been performed based on patient satisfaction questionnaires, resulting in favorable outcomes.[52,74-76] Other studies have been performed using biomechanical testing variables. Results indicate that orthotics for abnormal subtalar joint pronation may be effective in controlling the amount and velocity of calcaneal eversion and the amount of tibial internal rotation.[1,32,55,77,79,82] The amount of pronation occurring while using orthotics has also been shown to decrease.[80] However, results were not conclusive regarding studies of the time required to reach full pronation or the time spent in that position.[78,81] In addition, research concerning changes in lower leg or foot muscle activity while using orthotics reports variable results.[47-50]

The prescription of foot orthotics for abnormal subtalar joint pronation involves many factors, including the anatomy and biomechanics of the foot, ankle, and subtalar joint, changes in structure or function that may have occurred due to the abnormal pronation, selection of an appropriate material, decision regarding the type of orthotic and appropriate posting methods, and the effectiveness of the various orthotics. All of these factors must be taken into consideration when an orthotic is prescribed for a specific patient, regardless of whether prescription is completed by a physician, physical therapist, or another clinician.

APPENDIX

November 9, 1995

Attention: Till Davenport
Mosby Yearbook
Library Services
11830 Westline Industrial Dr.
Saint Louis, MO 63146

To whom it may concern:

I am a graduate student in Physical Therapy at the University of North Dakota in Grand Forks. I am currently working on my Independent Study Report regarding the prescription of orthotics. There is a figure used in a book called *Atlas of Orthotics: Biomechanical Principles of Application* published by your company in 1975 (then known as The C.V. Mosby Company) that I would like to use in my Independent Study Report. I am writing this letter to obtain your permission to use this figure.

I spoke with a representative from your company on the telephone and was told that I should request this in writing and that I could get permission that way. Enclosed you will find a photocopy of the figure I would like to use (Fig. 13-5 on page 260 of this book) and a form letter. I would appreciate it if you would sign the letter granting me permission to use this figure in my Study and return it in the enclosed self-addressed envelope. Thank you very much.

Sincerely,

Kari Rafteseth

Kari Rafteseth
Graduate Physical Therapy Student
University of North Dakota

encl

Permission to Use Previously Published Material
in an Independent Study Report

I hereby give Kari Rafteseth permission to use Figure 11.5 on page 260 of the *Atlas of Orthotics: Biomechanical Principles and Application* (published in 1975 by The C.V. Mosby Company) for academic educational purposes in her Independent Study Report.

Signature *Estrella B. Davenport* Date *12/4/95*

Estrella B. Davenport, Manager
Library Services and Permissions

Note: Please use standard credit line as indicted below -

Mosby-Year Book, Inc.
11830 Westline Industrial Drive
St. Louis, MO 63146

Permission is granted for non-exclusive use of the material specified, provided credit is given which acknowledges the author(s) or editor(s), title, edition, city, year of publication, and publisher. } *credit line*

Date

Permissions Department

REFERENCES

1. McCulloch MU, Brunt D, Vander Linden D. The effect of foot orthotics and gait velocity on lower limb kinematics and temporal events of stance. *J Orthop Sports Phys Ther.* 1993;17:2-10.

2. Gross ML, Napoli RC. Treatment of lower extremity injuries with orthotic shoe inserts. An overview. *Sports Med.* 1993;15:66-70.

3. Donatelli RA. Abnormal biomechanics. In: Donatelli R, Wolf SL, eds. *The Biomechanics of the Foot and Ankle.* Philadelphia, Pa: FA Davis Company; 1990:32-33,41-55.

4. Berenter RW, Kosai DK. Various types of orthoses used in podiatry. *Clin Podiatr Med Surg.* 1994;11:219-229.

5. Henderson W, Lamoreux L. The orthotic prescription derived from a concept of basic orthotic functions. *Bull Prosthet Research.* 1969;44:89-96.

6. Bordelon RL. *Surgical & Conservative Foot Care. A Unified Approach to Principles and Practice.* Thorofare, NJ: SLACK Incorporated; 1988:24,37,41.

7. Donatelli RA. Normal anatomy and biomechanics. In: Donatelli R, Wolf SL, eds. *The Biomechanics of the Foot and Ankle.* Philadelphia, Pa: FA Davis Company; 1990:8,14-19,28.

8. Norkin CC, Levangie PK. The ankle-foot complex. In: *Joint Structure & Function. A Comprehensive Analysis.* 2nd ed. Philadelphia, Pa: FA Davis Company; 1992:379-418.

9. Sammarco GJ. Anatomy of the foot and ankle. In: Sammarco GJ, ed. *Foot and Ankle Manual.* Malvern, Pa: Lea & Febiger; 1991:7.

10. Sangeorzan BJ. Subtalar joint: morphology and functional anatomy. In: Stiehl BJ, ed. *Inman's Joints of the Ankle.* Baltimore, Md: Williams & Wilkins; 1991:31-38.

11. Sangeorzan BJ. Biomechanics of the subtalar joint. In: Stiehl JB, ed. *Inman's Joints of the Ankle.* Baltimore, Md: Williams & Wilkins; 1991:65-73.

12. Mann RA. Biomechanics of the foot. In: *Atlas of Orthotics: Biomechanical Principles and Application.* St. Louis, Mo: The CV Mosby Company; 1975:257-266.

13. Klenerman L. Functional anatomy. In: Klenerman L, ed. *The Foot and Its Disorders.* 2nd ed. Boston, Mass: Blackwell Scientific Publications; 1982:19,22.

14. Mann RA. Biomechanics of the foot and ankle. In: Sammarco GJ, ed. *Foot and Ankle Manual.* Malvern, Pa: Lea & Febiger; 1991:34-39.

15. Rockar PA, Jr. The subtalar joint: anatomy and joint motion. *J Orthop Sports Phys Ther.* 1995;21:361-372.

16. Goss CM. *Gray's Anatomy.* 29th Am ed. Philadelphia, Pa: Lea & Febiger; 1973.

17. Warwick R, Williams P, eds. *Gray's Anatomy.* 35th Br ed. Philadelphia, Pa: W. B. Saunders Company; 1973.

18. Kapandji IA. Subtalar (talocalcanean) joint. In: *The Physiology of the Joints.* New York, NY: Churchill Livingstone; 1970:160.

19. Root ML, Orien WP, Weed JH. *Normal and Abnormal Function of the Foot.* Los Angeles, Calif: Clinical Biomechanics Corporation; 1977.

20. Blake RL, Ferguson H. Foot orthosis for the severe flatfoot in sports. *J Am Podiatr Med Assoc.* 1991;81:549-555.

21. Richie DH Jr, Olson WR. Orthoses for athletic overuse injuries. Comparison of two component materials. *J Am Podiatr Med Assoc.* 1993;83:492-498.

22. Moorhead J, Wobeskya L. Evolutionary aspects of foot disorders. *J Am Podiatr Med Assoc.* 1995;85:209-213.

23. Hutton WC, Stott JRR, Stokes IAF. The mechanics of the foot. In: Klenerman L, ed. *The Foot and Its Disorders.* 2nd ed. Boston, Mass: Blackwell Scientific Publications; 1982:31,30-40.

24. Saltzman CL, Nawoczenski DA. Complexities of foot architecture as a base of support. *J Orthop Sports Phys Ther.* 1995;21:354-360.

25. Hunter S. Rehabilitation of foot injuries. In: Prentice WE, ed. *Rehabilitation Techniques in Sports Medicine.* 2nd ed. St. Louis, Mo: Mosby Year Book, Inc; 1994:450-461.

26. Bordelon RL. Clinical assessment of the foot. In: Donatelli R, Wolf SL, eds. *The Biomechanics of the Foot and Ankle.* Philadelphia, Pa: FA Davis Company; 1990:85,91-92,95.

27. Janisse DJ. Indications and prescriptions for orthoses in sports. *Orthop Clin North Am.* 1994;25:95-107.

28. Blake RL, Ferguson HJ. Effect of extrinsic rearfoot posts on rearfoot position. *J Am Podiatr Med Assoc.* 1993;83:447-456.

29. Johanson MA, Donatelli R, Wooden MJ, Andrew PD, Cummings GS. Effects of three different posting methods on controlling abnormal subtalar pronation. *Phys Ther.* 1994;74:149-158.

30. Saye DE. The foot: biomechanics and orthotics. *Ostomy/Wound Management.* 1993;39:46-54.

31. Kannus VPA. Evaluation of abnormal biomechanics of the foot and ankle in athletes. *Br J Sports Med.* 1992;26:83-89.

32. Smith LS, Clarke TE, Hamill Cl, Santopietro F. The effects of soft and semi-rigid orthoses upon rearfoot movement in running. *Podiatr Sports Med.* 1986;76:227-233.

33. Clarke TE, Frederick EC, Hamill CL. The effects of shoe design parameters on rearfoot control in running. *Med Sci Sports Exer.* 1983;15:376-381.

34. Santopietro FJ. Foot and foot-related injuries in the young athlete. *Clin Sports Med.* 1988;7:564.

35. Siegler S, Chen J, Schenck CD. The three dimensional kinematics and flexibility characteristics of the human ankle and subtalar joint. *J Biomech Eng.* 1988;110(pt. 1):364-373.

36. Rose GK. *Orthotics: Principles and Practice.* London, England: William Heinemann Medical Books; 1986:21-27,38-69,73-75,196-218,255.

37. Kirby KA. Rotational equilibrium across the subtalar joint axis. *J Am Podiatr Med Assoc.* 1989;79:1-14.

38. Norkin C. Gait analysis. In: O'Sullivan SB, Schmitz TJ, eds. *Physical Rehabilitation: Assessment and Treatment.* Philadelphia, Pa: FA Davis Company; 1988:198.

39. Wooden MJ. Biomechanical evaluation for functional orthotics. In: Donatelli R, Wolf SL, eds. *The Biomechanics of the Foot and Ankle.* Philadelphia, Pa: FA Davis Company; 1990:143-145.

40. Blake RL, Ferguson H. Extrinsic rearfoot posts. *J Am Podiatr Med Assoc.* 1992;82:202-207.

41. Rodgers MM. Dynamic foot biomechanics. *J Orthop Sports Phys Ther.* 1995;21:306-316.

42. Harris GF. Analysis of ankle and subtalar motion during human locomotion. In: Stiehl JB, ed. *Inman's Joints of the Ankle.* 2nd ed. Baltimore, Md: Williams & Wilkins; 1991:80-81.

43. Donatelli RA, Wooden MJ. Biomechanical orthotics. In: Donatelli R, Wolf SL, eds. *The Biomechanics of the Foot and Ankle.* Philadelphia, Pa: FA Davis Company; 1990:193-197,200-201.

44. Tiberio D. Pathomechanics of structural foot deformities. *Phys Ther.* 1988;68:1840-1849.

45. Michaud TC. *Foot Orthoses and Other Forms of Conservative Foot Care.* Baltimore, Md: Williams & Wilkins; 1993:58-66,76-77,159-160,203-212.

46. Mueller MJ, Host JV, Norton BJ. Navicular drop as a composite measure of excessive pronation. *J Am Podiatr Med Assoc.* 1993;83:198-202.

47. Mann RA, Inman VT. Phasic activity of the intrinsic muscles of the foot. *J Bone Joint Surg.* 1964;46A:469-481.

48. Gray ER. The role of leg muscles in variations of the arches in normal and flat feet. *Phys Ther.* 1969;49:1084-1088.

49. Basmajian JV, Stecko G. The role of muscles in arch support of the foot. *J Bone Joint Surg.* 1963;45A:1184-1190.

50. Tomaro J, Burdett RG. The effect of foot orthotics on the EMG activity of selected leg muscles during gait. *J Orthop Sports Phys Ther.* 1993;18:532-536.

51. Giannini S, Catani F, Ceccarelli F, Girolami M, Benedetti MG. Kinematic and isokinetic evaluation of patients with flat foot. *Ital J Orthop Traum.* 1992;18:241-251.

52. Moraros J, Hodge W. Orthotic survey. Preliminary results. *J Am Podiatr Med Assoc.* 1993;83:139-148.

53. Rome K. A study of the properties of materials used in podiatry. *J Am Podiatr Med Assoc.* 1993;81:73-83.

54. Rome K. Behavior of orthotic materials in chiropody. *J Am Podiatr Med Assoc.* 1990;80:471-478.

55. Cornwall MW, McPoil TG. Footwear and foot orthotic effectiveness: a new approach. *J Orthop Sports Phys Ther.* 1995;21:337-344.

56. Murphy EF, Burstein AH. Physical properties of materials including solid mechanics. In: *Atlas of Orthotics: Biomechanical Principles and Application.* St. Louis, Mo: The CV Mosby Company; 1975:3,22-23.

57. Lewis G, Tan T, Shiue YS. Characterization of the performance of shoe insert materials. *J Am Podiatr Med Assoc.* 1991;81:418-424.

58. Olson WR. Orthoses. An analysis of their component materials. *J Am Podiatr Assoc.* 1988;78:203-206.

59. Bordelon RL. Orthotics. In: Sammarco GJ, ed. *Foot and Ankle Manual.* Malvern, Pa: Lea & Febiger; 1991:329,333,335.

60. Cavanaugh PR. Inserts, arch supports, and orthotics. In: *The Running Shoe Book.* Mountain View, Calif: Anderson World, Inc; 1980:250-253.

61. Weik DA, Martin WJ. Use of soft heat-molded orthoses in sports. A clinical analysis. *J Am Podiatr Med Assoc.* 1993;83:529-533.

62. Brodsky JW, Kourash S, Stills M, et al. Objective evaluation of insert material for diabetic and athletic footwear. *Foot Ankle.* 1988;9:111.

63. Cary JM, Lusskin R, Thompson RG. Prescription principles. In: *Atlas of Orthotics: Biomechanical Principles and Application.* St. Louis, Mo: The CV Mosby Company; 1975:235-239.

64. Evanski PM. Easing the pain of common foot problems. Can you justify using orthotics? *Patient Care.* 1991;25:40.

65. Roy S, Irvin R. Injuries to the running athlete-particularly the long-distance runner. In: *Sports Medicine: Prevention, Evaluation, Management, and Rehabilitation.* Englewood Cliffs, NJ: Prentice-Hall, Inc; 1983:443-445.

66. Jahss MH. Shoes and shoe modifications. In: *Atlas of Orthotics: Biomechanical Principles and Application.* St. Louis, Mo: The CV Mosby Company; 1975:275-278.

67. Thomas CL, ed. *Taber's Cyclopedic Medical Dictionary.* 17th ed. Philadelphia, Pa: FA Davis Company; 1993:430,611,846,1554,1699.

68. Campbell G, Newell E, McLure M. Compression testing of foamed plastics and rubbers for use as orthotic shoe insoles. *Prosthet Orthot Int.* 1982;6:48.

69. McPoil TG, Cornwall MW. Rigid versus soft foot orthoses. A single subject design. *J Am Podiatr Med Assoc.* 1991;81:638-642.

70. Tuck WH. Surgical footwear and appliances. In: Klenerman L, ed. *The Foot and Its Disorders.* 2nd ed. Boston, Mass: Blackwell Scientific Publications; 1982:420.

71. Bates BT, Osternig LR, Mason B, James LS. Foot orthotic devices to modify selected aspects of lower extremity mechanics. *Am J Sports Med.* 1979;7:338-342.

72. White J. Custom shoe therapy: current concepts, designs, and special considerations. *Clin Podiatr Med Surg.* 1994;11:259-270.

73. Hannaford DR. Soft orthoses for athletes. *J Am Podiatr Med Assoc.* 1986;76:566.

74. Donatelli R, Hurlbert C, Conaway D, St. Pierre R. Biomechanical foot orthotics: a retrospective study. *J Orthop Sports Phys Ther.* 1988;10:205-212.

75. Gross ML, Davlin LB, Evanski PM. Effectiveness of orthotic shoe inserts in the long-distance runner. *Am J Sports Med.* 1991;19:409-412.

76. Blake RL, Denton JA. Functional foot orthoses for athletic injuries: a retrospective study. *J Am Podiatr Med Assoc.* 1985;75:359-362.

77. Taunton JE, Clement DB, Smart GW, Wiley JP, McNicol KL. A triplanar electrogoniometer investigation of running mechanics in runners with compensatory overpronation. *Can J Appl Sports Sci.* 1985;10:104-115.

78. Brown GP, Donatelli R, Catlin PA, Wooden MJ. The effect of two types of foot orthoses on rearfoot mechanics. *J Orthop Sports Phys Ther.* 1995;21:258-267.

79. Novick A, Kelley DL. Position and movement changes of the foot with orthotic intervention during the loading response of gait. *J Orthop Sports Phys Ther.* 1990;11:301-312.

80. Eng JJ, Pierrynowski MR. The effect of soft foot orthotics on three-dimensional lower-limb kinematics during walking and running. *Phys Ther.* 1994;74:836-844.

81. Rodgers MM, LeVeau BF. Effectiveness of foot orthotic devices used to modify pronation in runners. *J Orthop Sports Phys Ther.* 1982;4:86-90.

82. Nawoczenski DA, Cok TM, Saltzman CL. The effect of foot orthotics on three-dimensional kinematics of the leg and rearfoot during running. *J Orthop Sports Phys Ther.* 1995;21:317-327.

83. Cook S, Kester M, Brunet M, Haddad RJ. Biomechanics of running shoe performance. *Clin Sports Med.* 1985;4:619-626.

84. Nigg B, Bahlsen A, Denoth J, Luethi S, Stacoff A. Factors influencing kinetic and kinematic variables in running. In: Nigg B, ed. *Biomechanics of Running Shoes.* Champaign, Ill: Human Kinetics Publishers; 1986:139-159.

85. Rose GK. Correction of the pronated foot. *J Bone Joint Surg Br.* 1962;44:642-647.

86. Sanner WH. Clinical methods for predicting the effectiveness of functional foot orthoses. *Clin Podiatr Med Surg.* 1994;11:280.