SPORTS MEDICINE & FOOT ORTHOSES

Epidemiology and Mechanisms of Running Injuries:

Biomechanical and foot orthotic design issues

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Introduction

One of the key applications of prescription foot orthoses is in the management of sport and occupational injuries. Perhaps the most prevalent types of injuries are related to running and high impact activity. The current *Industry Bulletin* has been modified from a lecture given by the author last March at the Ontario Society of Chiropodists conference.

We hope that it will interest our customers and that it might help to create food for thought in their daily clinical practice. The purpose of this *Bulletin* is to present the epidemiology of running injuries, biomechanical aspects of injury and foot orthotic design issues.

Epidemiology of Running Injuries

Running continues to be one of the preferred methods of improving and maintaining one's fitness. It is estimated that approximately 40 million North Americans are recreational runners. With this level of participation, there continues to be a high incidence of overuse injuries associated with running. In a recent epidemiological survey study of 2429 athletes in Australia, Baquie and Bruckner (1) reported that runners (12.3%) were the second most commonly injured athletes that presented over a 12-month period. Australian football players were the most frequently injured (13.3%).

The sports medicine community has conducted epidemiological studies that indicate that the most common sites of running injuries include the knee, tibia, Achilles tendon and plantar fascia. In 1981, Clement et al. (3) reported from their survey of 1650 patients that patellofemoral pain syndrome (25.8%), tibial stress syndrome (13.2%), Achilles peritendinitis (6%), plantar fasciitis (4.7%) and patellar tendinitis (4.5%) were the 5 most common diagnoses in runners. In a subsequent study in 1991, MacIntyre et al. (7) reported on 4173 runners over a 5-year period. These investigators reported that the five most common pathologies that presented were patellofemoral pain, tibial stress syndrome, Achilles tendonitis, plantar fasciitis and iliotibial band syndrome.

The etiological factors contributing to these injuries have been identified as training error, muscle dysfunction and flexibility, footwear, training surfaces and biomechanical factors (3,7). A collaborate effort amongst podiatric, sports medicine and physical therapy disciplines will ensure the successful identification and management of these factors. The prescription of custom foot orthoses is one modality prescribed as a means of addressing biomechanical etiology in conjunction with physical therapy and shoe gear.

This article will focus on the design and materials choices available to the prescriber of custom foot orthoses to address the contributing biomechanical factors associated with overuse running injuries. It is the author's intention to provide the reader with a full description of the rationale, application, and material and design choices for running foot orthoses. This article is from the perspective of the prescription foot orthotic laboratory who is in the advantageous position of receiving work from a wide variety of podiatrists and chiropodists who have varying prescribing techniques.

Biomechanical Aspects of Mechanism of Injury

When considering the etiology of running injuries, one must consider a number of contributing variables. Training variables are almost always factors including running distance and intensity, the running surface, footwear and inclusion of stretching. Anatomical variables also contribute to overuse injuries and so one must keep in mind foot architecture, range of motion, alignment, strength and

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flexibility. Although research has presented equivocal results in linking these factors to injury, there are hypothesized mechanisms that may help to explain why we see such a high incidence of running injuries in the excessive pronator. The main focus of this *Industry Bulletin* will be on the biomechanical variables both kinematic and kinetic.

In the late 1970's, several investigators began to explore the mechanism of running injuries. One of the initial proposed mechanisms was by James et al. (4) who suggested that the decoupling of lower extremity mechanics might contribute to overuse running injuries. The basis for this mechanism is that the rearfoot and the knee are linked mechanically via the subtalar joint. The motions of the foot thereby influence knee mechanics.

James et al. and others identified that internal tibial rotation is associated with knee flexion and rearfoot (calcaneal) eversion. James et al. suggested that these motions should be synchronous, that is, peak knee flexion (KF) and internal tibial rotation (ITR) should occur at approximately the same time as peak rearfoot eversion (RF-EV). The reversal of these motions (knee extension, external tibial rotation and rearfoot inversion) should occur at approximately the same in following mid-stance.

James et al. postulated that this is not the case with excessive pronators. In this case, there are two clinical scenarios that can present. The first is when the RF begins to invert (INV) while the knee continues to flex. In excessive pronators, the degree of KF reaches a greater degree (9) causing an increase in retropatellar compressive forces (Diagram #1). As the STJ supinates and the knee continues to flex, external tibial rotation (ETR) is initiated with RF-INV and thus torsional stress is placed on the soft tissues about the knee and ankle. Increased compressive forces and torsional stress may contribute to the development of PFPS, other knee and Achilles injuries.

Another scenario is when RF-EV is prolonged beyond midstance, the talus and tibia will continue to internally rotate. If the knee begins to extend while the rearfoot continues to evert and the tibia internally rotates, torsional stress will be placed on the knee and within the tibia. Results have been found that excessive pronators may either exhibit early RF-INV or prolonged RF-EV (Diagram #2).

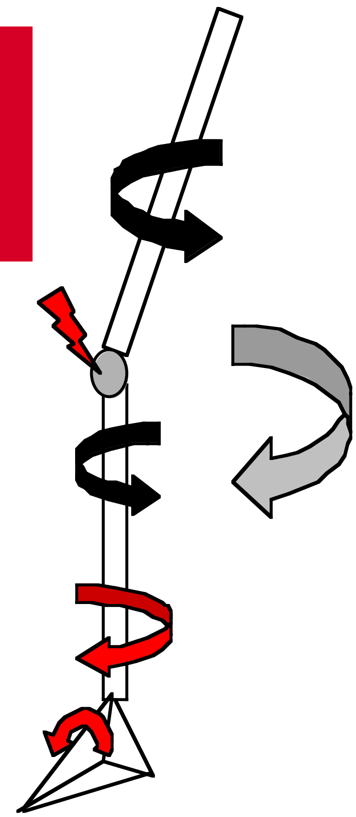
How Excessive Pronators Are Mechanically Different

McClay and Manal (8) have reported on the differences between runners with normal running mechanics and those with excessive pronation. In a 3-D kinematic analysis of the rearfoot and knee, excessive pronators exhibited:

- Rearfoot eversion at heel strike;
- Twice the peak eversion angle;
- Higher eversion and dorsiflexion velocities;
- Greater peak knee flexion angle;
- Lesser peak adduction angle and excursion; and
- Greater peak knee flexion velocity.

DIAGRAM 1 ~

**Clinical Scenario #1:
RF inversion initiates while knee continues to undergo flexion causing stress to the knee.**



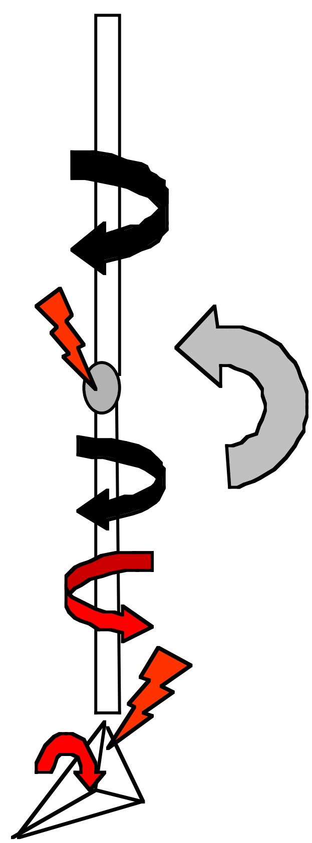


DIAGRAM 2 ~

**Clinical Scenario #2:
RF eversion continues beyond midstance. Knee extension is initiated while the RF continues to evert, causing stress to the ankle and knee.**

Biomechanics of Running

In order to understand the rationale for the design and application of foot orthoses for running, it is important to first consider the mechanics of running and how they differ from walking. The general goals of orthotic therapy are to control motion, control muscular activity and to provide shock attenuation for increased ground reaction force (GRF) and impact. Subotnick (14,15) has reported on the fundamental differences between walking and running. A critical difference and one of the key considerations behind the design of a functional orthoses for running is base of gait. There is a characteristic difference in the base of gait relative to the line of progression in running and the effect this has on running limb varus. Subotnick (14,15) and Cavanagh (2) describe that during running the base of gait approaches zero and that there is an increased functional running limb varus during running that is due to the fact that the feet contact the ground directly under the body's centre of mass (2,5,13). Increased hip adduction (13) during running, results in an increased varus attitude of the plantar rearfoot and forefoot in the frontal plane (5).

Kirby (5) has recommended that increased functional running limb varus needs to be addressed in the design of a prescription foot orthoses. The increase of running limb varus has been identified as being caused by increased femoral and tibial adduction, and increased inversion of the calcaneus prior to the support phase of running (5). Kirby reports that this effect may add an additional 5 degrees of tibial and rearfoot varus while running compared to walking. The orthoses need to have increased intrinsic varus posting with or without a medial heel skive (5). One study has suggested that the concept of functional running limb varus is a "myth", however, there is some controversy over the running velocity used in their analysis (16).

Another well documented biomechanical difference between walking and running is the magnitude of vertical forces or ground reaction force (GRF)(9). In 1985, Subotnick (15) reported that ground reaction forces approached 3 times body weight whereas walking GRF was roughly the same as body weight. More recently, Ounpuu (13) reported that vertical ground reaction force is 1.3-1.5 times body weight for walking and 2-3 times body weight for running. The increased magnitude of GRF and, hence, increased moments about the subtalar joint lead to a foot pronation velocity that approximates five times greater than walking (5).

The net effect of these three biomechanical factors is that the foot and ankle are subject to vertical forces (GRF) of a higher magnitude, the plantar aspect of the foot is positioned in a mechanically disadvantageous position in the frontal plane prior to heel strike because of hip adduction and increased functional varus, and thus the velocity of pronatory motion increases by a factor of five relative to walking.

Foot Orthoses for Running

The biomechanical differences that exist between walking and running have led many podiatrists to prescribe different orthoses for these activities. As different as the activities are, so too are the foot types that present to the podiatrist. We still are not clear on how exactly foot orthoses function. Traditionally, we have speculated that they control the skeletal movement, however, these clinical observations have been merely anecdotal and the scientific literature has reported that this may only be true to a small degree (6,10). Nigg and colleagues (11,12) have proposed a new model that inserts have an effect on minimizing muscle work, increasing proprioception and comfort.

The question of how foot orthoses actually function has inspired a new interest in podiatric biomechanical research. The actual insert or orthotic devices used in these studies are somewhat questionable. Very few researchers have not described the design of orthoses employed nor have they used custom functional devices from neutral suspension casts. The term "orthotic" or "insert" has been used indiscriminately in the literature (5) and has been used to describe everything from a manufacturer insole to a true custom foot orthoses. Whether it is skeletal control or whether an orthoses informs musculature through proprioception or a combination of both, we know that in most instances there are positive clinical outcomes with orthoses intervention (5,6).

The general objectives of designing custom foot orthoses for runners are 1) to dissipate the impact associated with the increased GRF involved in running, and 2) to support and control the increased functional running limb varus present during running mechanics.

Many practitioners prescribe rigid or semi-rigid functional orthoses for running applications. Our *Functional* and *Sport* models are designed to provide a high level of functional control with a moderate level of shock attenuation. Both of these models can be made of polypropylene, carboplastic or graphite composite materials of a rigid or semi-rigid thickness. Polypropylene orthoses can be either vacuum-formed or "milled" (machined using a computer numerically controlled

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(CNC) milling machine) from a 1–11/2" thick block of polypropylene using our Automated Orthotic Manufacturing System (AOMS). Composite materials, unfortunately, cannot be milled. *Functional* and *Sport* orthoses from carboplastics (*XT Sprint)* and graphite composites *(TL 2100)* must be vacuum-formed.

Our *Direct Milled Functional* and *Sport* models are extremely precise, have superior speed of memory and are more durable than their vacuum-formed equivalent. (As heat is not involved in the manufacturing process, the integrity of the material's polymer chain is not disturbed.) *Direct milled* devices can be designed in very precise detail, as all parameters of shell shape and thickness are programmable.

There are applications when a practitioner wants a device with a moderate level of functional control combined with a high level of shock attenuation. Our *Mold* and *Sport Impact* devices are designed for these applications. *Molds* function semi-flexible and consist of a polypropylene shell (thickness tailored to body weight), laminated with a Poron arch fill and are very effective in managing rigid cavus or hypersensitive feet. *Sport Impact* devices are constructed the same way but with a thicker shell material to achieve greater rigidity. Designed to function semi-rigid, *Sport Impact*s are indicated when a higher degree of functional control and high level of shock attenuation is desired. Alternate shell and arch fill materials are available on both devises for anomalous cases.

Cover materials are another key component of running orthoses as they can contribute greatly to the device's ability to attenuate shock and if ordered full length, mitigate orthoses migration in the shoe. Our lab standard cover for *Sport* models is 3mm full-length neoprene, a very durable material with considerable shear strength and excellent shock absorbing properties. Our lab standard for *Molds* and *Sport Impacts* is a 3mm full length EVA (Microcel Puff) top cover with a 1.5mm EVA (Nyplex) bottom cover. These two EVA variants used together create a very durable and extremely shock absorbent combination. Other commonly ordered cover materials for running orthoses include Poron & vinyl and Poron & EVA in a variety of thickness. Patient pathology, device application, shoe gear type, shoe gear volume and patient preference are all important considerations when choosing the right top cover.

For more information about our orthoses and materials, please refer to our *Products & Materials Information* brochure or contact Janice Stewart (extension 19) or Christopher Mac-Lean (extension 15) at 1-800-848-0838 or via e-mail: jstewart@parisorthotics.com or cmaclean@parisorthotics.com

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