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Edited by

Dan Tunstall Pedoe

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Authors and Chairpersons

Sir Roger Bannister CBE
NEUROLOGIST, FORMER MASTER OF PEMBROKE COLLEGE, OXFORD, UK

Professor Claude Bouchard
EXECUTIVE DIRECTOR, PENNINGTON BIOMEDICAL RESEARCH CENTER,
HUMAN GENOMICS LABORATORY, BATON ROUGE, LOUISIANA, USA

Christopher Brasher CBE
FOUNDER & PRESIDENT, THE LONDON MARATHON

Dr Richard Budgett
DIRECTOR OF MEDICAL SERVICES, BRITISH OLYMPIC MEDICAL CENTRE, LONDON, UK

Dr Alan Donnelly
SENIOR LECTURER, DEPARTMENT OF PHYSICAL EDUCATION AND SPORTS SCIENCE, UNIVERSITY OF LIMERICK,
LIMERICK, IRELAND

Dr Randy Eichner
PROFESSOR OF MEDICINE, HEMATOLOGY-ONCOLOGY SECTION,
UNIVERSITY OF OKLAHOMA HEALTH SCIENCES CENTER, OKLAHOMA, USA

Dr Lawrence Folinsbee
ENVIRONMENTAL MEDIA ASSESSMENT BRANCH, NATIONAL CENTER FOR ENVIRONMENTAL ASSESSMENT, US
ENVIRONMENTAL PROTECTION AGENCY, RESEARCH TRIANGLE PARK, NC, USA

Dr Gerrit Van Hall
THE COPENHAGEN MUSCLE RESEARCH CENTER, RIGSHOSPITALET (UNIVERSITY HOSPITAL), COPENHAGEN,
DENMARK

Professor Adrianne Hardman
DEPARTMENT OF PHYSICAL EDUCATION, SPORTS SCIENCE AND RECREATION MANAGEMENT,
LOUGHBOROUGH UNIVERSITY, LEICESTERSHIRE, UK

Dr Jørn Helge
THE COPENHAGEN MUSCLE RESEARCH CENTER, RIGSHOSPITALET (UNIVERSITY HOSPITAL), COPENHAGEN,
DENMARK

Professor Mike Lambert
DIRECTOR OF HIGH PERFORMANCE CENTRE, MRC/UCT BIOENERGETICS OF EXERCISE RESEARCH UNIT,
FACULTY OF HEALTH SCIENCES, UNIVERSITY OF CAPE TOWN,
SPORT SCIENCE INSTITUTE OF SOUTH AFRICA, NEWLANDS, SOUTH AFRICA

Dr Barry Maron
DIRECTOR, HYPERTROPHIC CARDIOMYOPATHY CENTER,
MINNEAPOLIS HEART INSTITUTE FOUNDATION, MINNEAPOLIS, MINNESOTA, USA

Dr David Martin
EMERITUS PROFESSOR, DEPARTMENT OF CARDIOPULMONARY CARE SCIENCES, GEORGIA STATE UNIVERSITY,
ATLANTA, GEORGIA, USA

Dr Alan Maryon-Davis
SENIOR LECTURER IN PUBLIC HEALTH MEDICINE,
DEPARTMENT OF PUBLIC HEALTH SCIENCES, KING'S COLLEGE LONDON, LONDON, UK

Professor Ron Maughan
PROFESSOR OF HUMAN PHYSIOLOGY, DEPARTMENT OF BIOMEDICAL SCIENCES, UNIVERSITY MEDICAL SCHOOL, FORESTERHILL, ABERDEEN, UK

Professor William Morgan
DIRECTOR, EXERCISE PSYCHOLOGY LABORATORY, DEPARTMENT OF KINESIOLOGY, UNIVERSITY OF WISCONSIN-MADISON, MADISON, WISCONSIN, USA

Professor Eric Newsholme
EMERITUS PROFESSOR OF BIOCHEMISTRY, MERTON COLLEGE, OXFORD, UK

Professor Timothy Noakes
MRC/UCT BIOENERGETICS OF EXERCISE RESEARCH UNIT, FACULTY OF HEALTH SCIENCES, UNIVERSITY OF CAPE TOWN, SPORT SCIENCE INSTITUTE OF SOUTH AFRICA, NEWLANDS, SOUTH AFRICA

Dr Bente K Pedersen
DEPARTMENT OF INFECTIOUS DISEASES, RIGSHOSPITALET (UNIVERSITY HOSPITAL), COPENHAGEN, DENMARK

Mr Trevor Prior
CONSULTANT PODIATRIST, ST LEONARD'S PRIMARY CARE CENTRE, LONDON, UK

Professor Peter Radford
PROFESSOR OF SPORT SCIENCES, DEPARTMENT OF SPORTS SCIENCES, BRUNEL UNIVERSITY, WEST LONDON, UK

Professor Peter Raven
DEPARTMENT OF INTEGRATIVE PHYSIOLOGY, UNIVERSITY OF NORTH TEXAS HEALTH SCIENCE CENTER, FORT WORTH, TEXAS, USA

Dr William O Roberts
MINNHEALTH FAMILY PHYSICIANS, WHITE BEAR LAKE, MINNESOTA, USA

Professor Bengt Saltin
THE COPENHAGEN MUSCLE RESEARCH CENTER, RIGSHOSPITALET (UNIVERSITY HOSPITAL), COPENHAGEN, DENMARK

Professor Craig Sharp
PROFESSOR OF SPORT SCIENCE, DEPARTMENT OF SPORT SCIENCES, BRUNEL UNIVERSITY, WEST LONDON AND HONORARY RESEARCH FELLOW, UNIVERSITY OF STIRLING, UK

Dr Susan Shirreffs
LECTURER IN PHYSIOLOGY, DEPARTMENT OF BIOMEDICAL SCIENCES, UNIVERSITY MEDICAL SCHOOL, FORESTERHILL, ABERDEEN, UK

Dr Martyn Shorten
MANAGING PARTNER, BIOMECHANICA, PORTLAND, OREGON, USA

Dr Michael Stroud
SENIOR LECTURER IN MEDICINE & NUTRITION, CONSULTANT GASTROENTEROLOGIST INSTITUTE OF HUMAN NUTRITION, SOUTHAMPTON UNIVERSITY HOSPITALS TRUST, SOUTHAMPTON, UK

Dr Dan Tunstall Pedoe
MEDICAL DIRECTOR OF THE LONDON MARATHON, CONSULTANT CARDIOLOGIST, ST BARTHOLOMEW'S & HOMERTON HOSPITALS, LONDON, UK

Professor Clyde Williams
PROFESSOR OF SPORTS SCIENCE, DEPARTMENT OF PHYSICAL EDUCATION, SPORTS SCIENCE & RECREATION MANAGEMENT, LOUGHBOROUGH UNIVERSITY, LEICESTERSHIRE, UK

Dr Roger Wolman
THE ROYAL NATIONAL ORTHOPAEDIC HOSPITAL, LONDON, UK

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The four most common overuse injuries incurred by runners are associated with varus alignment of the lower extremity. In each case, the purported biomechanical link between impact and injury involves functional over-pronation.

In patello-femoral pain syndrome (or 'runner's knee'), for instance, excessive pronation and the associated internal tibial rotation is thought to cause the patella to move slightly from its normal alignment relative to the femoral condyles. The resulting increase in contact pressure in the patello-femoral joint leads to painful symptoms. In extreme cases, the high pressures cause degradation of the cartilage and underlying bone (chondromalacia patella).

Excessive pronation has also been implicated in some types of tibial stress syndrome, eg shin splints[8]. Functional over-pronation is thought to increase the tension in the Achilles tendon, overloading the insertion of the soleus where breakdown of the tibial surface may occur. Similarly, purported mechanisms of Achilles tendinitis include excessive pronation as a risk component. Violent motion of the tendon during impact may lead to micro-tears and tissue degeneration. It has also been suggested that functional over-pronation and internal tibial rotation produce torsional stresses in the tendon, with vascular impairment as a possible consequence[9]. Torsional stresses due to excessive pronation are also implicated in the aetiology of plantar fasciitis[10,11].

Pronation control in running shoes

Since the early 1980s, most running shoe manufacturers have included anti-pronation or motion control features in some or all of their products. Such features include stiffer cushioning, stiff heel counters, insole boards, medially posted midsoles, varus wedges and proprietary cushioning geometries. Some of these work by stiffening the shoe upper and midsole to physically restrain movement of the subtalar joint; others modify the geometry of the cushioning to reduce the lever arm of the ground reaction force about the subtalar joint — this reduces the torque that tends to promote pronation. Firmer, wider midsoles offer a greater lever arm to the ground reaction force, increasing angular displacement and pronation velocity. Softer midsoles increase shock attenuation and reduce angular velocity at the expense of greater rearfoot motion[12].

Shoes with a soft lateral border combined with a firmer medial post have been found to be effective at controlling pronation[13]. The soft lateral border is compressed on contact and attenuates shock and reduces the lever arm of the ground reaction force, while the firmer medial border resists excessive pronation. Upper constructions that encourage a close fit between the heel and the shoe also contribute to motion control[14].

The excessive pronation hypothesis is commonly used in shoe design and medical diagnoses. Treatments for running injuries, using orthotics, or specifically designed shoes to reduce pronation are often effective in relieving symptoms. Conventionally, athletes with pes planus are considered more likely to have hypermobile feet which

hyperpronate and require 'stable shoes'. Conversely, those with pes cavus are more likely to have hypomobile feet that pronate less and require more cushioned shoes.

Detailed mechanisms of injury and treatment through pronation control, however, are still not well understood. For instance, the movement coupling between eversion of the calcaneus and tibial rotation is not absolute. An in vitro study revealed that only 14–66% of calcaneal eversion was transferred to tibial rotation[15]. The situation is further complicated by the observation that movement coupling is less for athletes with pes planus and greater for those with pes cavus[16]. Recent studies suggest that variability in coupling may be more important than the degree of coupling per se[17]. It is also known that the talo-calcaneal joint has variable anatomy, with both two- and three-faceted joints commonly found[18,19]. An individual may have a different number of facets on left and right sides.

These findings add to the difficulty in making individual footwear prescriptions and confound the running shoe manufacturers' problem of having to meet the needs of a large population of customers with relatively few shoe models. Historically, the manufacturers' strategy was to make shoes with varying degrees of pronation control, offer some guidance on shoe selection and allow consumers to choose. Products increasingly have cushioning systems with integrated anti-pronation mechanisms that make the stability properties of a shoe more independent of the cushioning properties. These sophisticated shoe designs respond to increasing medial loads by stiffening, intending to provide greater resistance to pronation 'on demand'. Such designs aim to meet the needs of a wider range of runners with different foot types and pronation mechanics.

Shoe inserts

Shoe inserts are commonly used to correct lower extremity alignment problems and pronation. They reduce rearfoot motion by 1–2° (slightly less than the effect of a stability-oriented running shoe), particularly when combined with a stability shoe[20], but recent research into their effectiveness is equivocal. Nigg *et al*[21] compared the effects of six different orthotic inserts on rearfoot motion during running; none were significantly different from the non-insert condition. Stacoff *et al*[22] measured three-dimensional calcaneal and tibial rotations using markers placed on intra-cortical pins. Orthotics were found to have only small effects on tibio-calcaneal motions which were inconsistent among subjects, indicating that any effects are highly individual. It has been suggested that the proper role of shoe inserts is to reduce muscular work instead of aligning the skeleton or limiting motion[23].

Cushioning in running shoes

The impact between the foot and the ground during a running step has a peak force magnitude in excess of two times the athlete's bodyweight, and generates a shock wave that is transmitted through the musculoskeletal system. The impact shock wave has a

Glossary

AED: automated electric defibrillator — an apparatus for stopping fibrillation of the heart by application of an electric current to the chest wall

Allele: one of the alternative forms of a gene

Anhidrosis: failure to sweat

Autosomes: paired chromosomes other than the sex chromosomes; 22 pairs in man

Clo: the insulation required to maintain thermal comfort in a resting subject in a normally ventilated room at a temperature of 21 °C and humidity of <50%. It is a pragmatic definition and standard office dress is approximately 1 clo

Collagen: a protein structure of skin, tendon, bone, cartilage and other connective tissue

Concentric muscle contraction: muscular contraction that occurs as the muscle shortens

Core temperature: temperature of the central circulation and hypothalamus; the size of the core depends on climatic conditions and metabolic rate

Desmin: a structured protein in skeletal muscle that links Z discs of adjacent fibres

Dizygotic (DZ) twins: non-identical twins

EAC: exertion-associated collapse

Eccentric muscle contraction: a muscular contraction that occurs as the muscle lengthens

EHS: exertional heat stroke — a condition that occurs when endogenous heat production and exogenous heat gain are greater than heat dissipation to the environment

EMG: electromyography — an apparatus used to record electric currents generated in active muscle (muscle potentials)

EPO: erythropoietin — a hormone secreted in the kidney in response to a lowered oxygen content in the blood. It acts on the bone marrow to stimulate red blood cell production

F ratio: comparison of the between-family and within-family variance for VO_{2max}

Fast-twitch (FT) muscle fibre: type 2 muscle fibre

Gamow bag: a lightweight, portable, airtight bag in which a victim with altitude sickness can be repressurized using a foot pump similar to that used in rubber boats. The design includes a clear plastic observation window

Genotype: the genetic constitution of an individual

Haematocrit: red cell fraction of whole blood

Haptoglobin: a protein that binds haemoglobin of damaged red blood cells and is then removed from the circulation. A low or absent amount indicates red blood cell haemolysis or fragmentation

HCM: hypertrophic cardiomyopathy — a cardiac disease characterized by a hypertrophied and non-dilated left ventricle

HSPs: heat shock proteins — a family of proteins which acts as immunodominant antigens

Isometric muscle contraction: a muscle contraction that occurs with no change in muscle length

MASL: metres above sea level

Master's athlete: an adult individual who competes in events categorized by age, usually in five-year age bands. The lower limit varies to some extent by country and sport, but in the marathon it is often taken to be from age 40 in both genders. However, the World Veterans games is a biennial track-and-field championship for women >35 and men >40 years, which has been staged since 1975. *National Masters News*, the 'official world and US publication masters track and field, long distance running and race walking', defines masters as 'age 30+'

MET: metabolic equivalent. Multiple of resting metabolic rate

MET-hours: sum of average time per week spent in each activity x MET value of each activity

Monozygotic (MZ) twins: identical twins

Nebulin: a muscle structural protein

Phenotype: a set of observable characteristics of an individual as determined by genotype and environment

Polymorphism: the occurrence in the same population of two or more genetically determined phenotypes in such proportions that the rarest of these cannot be maintained purely by mutation

Respiratory exchange ratio (RER): the volume of carbon dioxide released during respiration compared to the volume of oxygen consumed

Respiratory quotient (RQ): the ratio of carbon dioxide produced to oxygen consumed; an old term now used for tissues or organs

Sarcolemma: the cell membrane of the muscle fibre

Sarcomere: the basic contractile unit of the myofibrils which are arranged end-to-end at the Z line and are composed of thin filaments (actin) and thick filaments (myosin); the thick and thin filaments slide over each other during contraction. Each muscle cell (fibre) contains up to several thousands myofibrils

Secular: occurring once in an age or century

Shell temperature: temperature of the skin and superficial tissues. The size of the shell depends on climatic conditions and metabolic rate

Sib: brother or sister

Slow-twitch (ST) muscle fibre: type 1 muscle fibre

STPD: standard temperature pressure dry — a means of normalizing samples of expired air to reference values

Telomere: end region of chromosomes

Titin: a large protein that links the end of the thick filament to the z disk in a muscle fibre

VO_2: oxygen uptake

VO_{2max}: maximal oxygen uptake

Wall ('hitting the wall'): a mythical barrier in marathon running describing a point at about 20 miles where many runners suddenly slow down and experience intense fatigue. This is probably multifactorial but can be caused by glycogen depletion of muscle

WBGT: wet bulb globe temperature — an index of heat stress

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