The effect of aging, obesity and diabetes on foot and general health and wellbeing, and its association with current and future footwear technologies

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Abstract

Changes in foot health trends are beginning to demand significant changes to foot health provision globally, for which appropriate provision to retail and health services is key. With the right input to innovation and design, footwear can help keep us fit and active and contribute to our overall wellbeing, creating exciting opportunities for the footwear market. Likewise, the development of orthotic materials, designs and manufacturing processes is enabling more complex solutions to equally complex developing foot conditions. There are three key issues driving the demand for specific footcare; the global increase in the number of people with diabetes, those who are obese and the fact we are all living longer. The populations of diabetic, elderly and obese adults require specific footcare solutions to meet the specific characteristics of their foot health issues such as wider-fit footwear and pressure relieving orthotic materials. Characteristics of these populations' feet relating to their morphology, tissue characteristics, vascular supply and sensation impact on their requirements from footwear. Additional characteristics relating to their overall health such as excess mass and instability additionally impact on the wear on the loading of the footwear and design features which may be beneficial.

Introduction

The global population is aging and becoming more overweight with greater prevalence of diabetes, particularly in the developed world. By 2025 it is estimated that 21% of developed countries population will be 65 years old or over.[1] This trend toward an older population has significant socio-economic repercussions, increasing demand on healthcare services due to increased prevalence of neuro-muscular disease and musculo-skeletal disorders. Additionally, Diabetes has now reached epidemic levels, affecting around 9.1% of the European population.[2] These place substantial pressure on the health care systems. Recent growth in the numbers of people with Diabetes is attributable to dietary changes and an increase in sedentary lifestyles in the developing and developed world. These changes have also lead to the prevalence of obesity is increasing, latest estimates identify 30-70% of European adults as overweight and 10-30% as obese.[3] Due to their conditions, these adults have specific foot health needs, which poses significant challenges. The successful management of these adults foot health has benefits for the wider health care system by maintaining their cardiovascular health and active involvement in the community. With the right input to innovation and design, footwear and orthotics can provide solutions to the challenges posed by these populations. Provision of "healthy footwear" (footwear that promotes improvement in, or maintenance of, foot health and thereafter general health) to a specific range of users is a challenge that requires effective co-operation between clinicians, researchers, technologists, designers and the footwear production industry. To establish the nature of the footwear and technology requirements of specific users, we must first fully define the consequences of aging, diabetes and obesity on the foot.

Diabetes

Diabetes affects blood glucose regulation and leads to changes throughout the body. It is associated with increased mortality, long-term complications lead to macrovascular problems such as stroke and peripheral arterial disease and microvascular complications such as kidney failure and neuropathy. Fifty percent of patients who have suffered from diabetes for more than 20 years develop peripheral neuropathy, affecting nerve function.[4] Combining this with stiffened plantar soft tissue results in type II diabetes being the most frequent non-traumatic cause of amputation of the lower limb.[5]

The anthropometry of a patient with diabetes may reflect that of a person who is over-weight; there is a well-reported association between diabetes and both BMI and waist measurements.[6] The altered morphology apparent in a person with diabetes includes the foot and lower limb.[7] Ill-fitting footwear has more than comfort implications for a person with diabetes, due to an increased risk of high-pressure regions on dry, vulnerable skin and therefore potential ulceration. Tight-fitting or narrow footwear is implicated as a precipitating factor in between 36-54% of amputations and preceding ulceration.[8,9] Despite the importance of a correctly fitting shoe for people with diabetes, it has been suggested that only 20% of patients wear correct fitting footwear.[10] The provision of footwear with suitable dimension and lack of seams for people with diabetes is therefore essential.

There is an increased perceived risk and incidence of falls in people with diabetes and this has been attributed to the presence of neuropathy, inherent associated conditions such as ocular degeneration and other characteristics of patients' gait including reduced walking speed, greater stance widths and tremor.[11,12] Literature reports reduced mobility and power at the ankles, reduced midfoot and calcaneal motion and impaired proprioception of the ankle frontal plane.[13,14] Changes in ground reaction forces in walking are also apparent in people with diabetes. These include lower minimal vertical, second peak vertical and increased medial-lateral ground reaction force in stance.[15] The stiffer foot leads to reduced centre of pressure excursion in both the medial-lateral and longitudinal axes of the foot and longer contact times.[13] It is likely, therefore, that both neuropathy and other characteristics of people with diabetes aggregate to decrease their stability; their footwear choice therefore should aim to ameliorate this deficit.

Specific localised changes are apparent in people with diabetes in the lower limbs and feet. Atrophy of intrinsic foot and ankle musculature have been demonstrated and linked to markers of neuropathy.[16,17] There is a close relationship between muscle volume and strength,[18] reflecting a reduction of musculo-skeletal ability in the lower limb of people with diabetes and potentially leading to altered foot architecture and abnormalities. Peripheral neuropathy is associated with hyperextension of the metatarsal-phalangeal joints, reduced mobility in the subtalar joint and clawing of the toes. In-turn these foot deformities increase the risk of callous formation and ulceration in people with diabetes by increasing local plantar pressures in the forefoot.[19,20] Barefoot plantar pressures in people with diabetes are higher in some foot regions in comparison to healthy controls, irrespective of the presence of neuropathy.[21] Elevated shear forces (>32%) are also evident and the occurrence of peak shear and pressure occurs at the same site more often in a neuropathic foot.[22] There is a higher relative risk of developing an ulcer in an area of elevated pressure (x4.7), also an area of callus (x11.0) and a previous ulceration site (x56.8).[23] Dryness of the foot skin resulting in callus under areas of increased pressures is evident in patients, with localised chiropody treatment reducing local plantar pressures by 26%.[24] There is also evidence that people with diabetes lose thickness and elasticity of their foot pads at the heel and metatarsal head, due to exposure of tissue to glucose, reducing the shock absorption capability of the foot.[25] Pre-fabricated and custom molded insoles reduce plantar pressure and internal stresses in people with diabetes and healthy patients in standing and walking, which potentially reduces the risk of ulceration. Suitable footwear to distribute plantar pressures obviously plays an important role in the treatment and prevention of ulceration of the foot in diabetes.[21,26]

Footwear recommendations for people with diabetes are widely available and it is a rapidly growing consumer and health care market. The management of footwear for people with diabetes requires the provision of large volume off-loading shoe, resulting in the wide-spread use of rocker footwear with molded insoles. More precise guidelines for rocker shoe design could be produced from recent literature which recommends a 95° apex angle, apex position at 60% of shoe length and 20° rocker angle may achieve an optimal balance for offloading different regions of the forefoot.[27] Ulcer relapse has reduced by over 50% in patients who wear prescribed therapeutic footwear as opposed to their own footwear, emphasising the importance in specialised footwear in the management of the foot in diabetes.[28] Despite the apparent success of interventions, the provision of therapeutic footwear to people with diabetes is hindered by lack of compliance. 18-24% of patients report that the style of the footwear is not cosmetically acceptable, resulting in only 22-36% of patients regularly wearing their footwear for a sufficient proportion of the day.[28–30] This underlines the importance of the development of a shoe that is both functional (incorporating research findings) and aesthetically pleasing for people with diabetes to increase compliance.

Ageing

The ageing population demonstrate an increase in body fat and reduction in lean body mass, reduced range of motion at joints, and reduced muscular strength.[31–33] Despite these limitations to physical activity and mobility, maintaining an active older adult population offers substantial socio-economic benefit, for which stable and comfortable footwear is an essential tool to maintaining mobility.

The neuro-muscular and musculo-skeletal deficits in older adults can lead to a significant reduction in the ability to balance and recover from perturbation. 1 in 3 adults over 65 years of age will fall each year and around half of these falls are at least in-part attributable to footwear features such as heel height, cushioning properties of the midsole, slip-resistance of outsole, height of the heel counter and midsole flare.[34–37] Factors influencing this increased risk in falls in older adults include reduced proprioception, reduced toe clearance in swing, increased gait variability, higher horizontal heel contact velocity and reduced ability to recover with enough force in an appropriate time.[38–40] All of which are attributable to reductions in lower limb muscular strength, flexibility, sensation and co-ordination with age. Footwear adaptations to reduce falls risk in the ageing population are evident in literature focusing on physical or sensory solutions. Physical solutions include altering sole geometry to increase toe clearance, or increasing the soles coefficient of friction.[41-42] Sensory solutions aim to increase proprioception, which has been achieved through higher shoe collars, midsole hardness adaptations and the inclusion of tactile or vibrating insoles.[42-44] Increasing the awareness of older adults of these recommendations is key.

In addition to general balance and motor-control issues, approximately 50-70% of people over 60 years of age in developed countries experience foot pain.[45] In America 20% of adults 50 years or over rate their foot health as fair or poor, compared to 14% of 21-34 year olds.[45] This decrease in foot health in older adults is attributable to a range of issues including bone and soft tissue deformity, vascular issues and neuro-muscular disease. Conditions associated with the skin and nails include thickened nails, hyperkeratosis (corns and calluses), heel fissures, blisters and warts. Issues can cause localised pain and the use of pressure reducing materials at these areas and adapting footwear and insole shapes to off-load painful sites are successful treatments. Bone and soft tissue deformities include a reduced ability to absorb shock at bursa sights due to the fat pads diminishing with age.[46] Flat feet (pes planus), hallux-valgus, hammer toe and lesser toe deformities are also prevalent after 60 years of age (9-25%).[47] These conditions may have direct impact on balance and stability in addition to being painful. Adaptations to footwear insoles and upper features such as wide toe-box footwear may be required to accommodate the foot.

In addition to bone and soft tissue deformity, vascular deterioration can instigate localised swelling (oedema), which has a high prevalence in older people and also negatively impacts on the fit and comfort of footwear. Recommendations therefore include adjustable footwear that enables the upper volume to be modified throughout the day i.e. Velcro fastened footwear. Neuromuscular changes with increasing age include a significant deterioration of kinaesthesia in the metatarsophalangeal and ankle joint[38]. The aforementioned use of sensory insoles aims to enhance sensorimotor input. The treatment modalities of the symptoms related to older peoples' feet therefore range from regular podiatric treatment such as nail cutting and callous removal to bespoke prescription footwear to accommodate specific foot geometries or provide specific sensations or pressure reduction.

Fully understanding the size and shape of the older persons' foot is essential in order to provide footwear that is a good fit for the ageing population to enhance comfort in healthy and symptomatic feet alike. Well-fitting footwear is also a preventative measure against further deterioration of older foot skin so should be encouraged. In Australia 80% of older people wear footwear that is too narrow or short for their foot,[48] in Japan this was reversed with 39% of older adults wearing shoes which were too loose.[49] Loose footwear poses a significant trip risk to wearers, particularly those whose balance, stability and toe-clearance is already compromised. Older peoples' foot size differs from commercially available footwear; demonstrating that footwear for older people may need to be produced on mass-customised lasts, or that more varied width fittings and adjustable footwear would be more suitable.

Obesity

Obesity is defined by the World Health Organisation (WHO) as a Body Mass Index (BMI) ($kg.m^{-2}$) greater than or equal to 30 $kg.m^{-2}$.[3] The principal cause of obesity is an energy imbalance between consumption and expenditure, hence the concurrent prevalence increase with the popularity of high energy foods and decreased daily physical activity in the developing world.[3] However, there are a myriad of factors which influence this relationship, including genetics, person specific metabolic and physiological states and health related behaviour. It follows that effective solutions that address obesity are multifaceted and focus on nutrition and physical activity,[50] with comfortable and well-fitting footwear being of obvious importance to the latter.

Obesity has numerous associated health consequences, in particular diabetes and musculoskeletal disorders or symptoms such as knee osteoarthritis and lower back pain. The importance of foot health is evident by the requirement for an individual who is obese to be physically active to maintain levels of cardiovascular and musculoskeletal health in addition to increasing energy expenditure to reduce weight. Poor foot health is debilitating and is related to reductions in community walking and participation in activity.[45] The anthropometrical impact of obesity is an increase in body size, mass and fat distribution centred on the trunk and abdomen. This centring of fat mass limits the range of motion at the trunk during sitting and standing, it also shifts the centre of mass anteriorly which has implications for balance and stability.[51,52] There is a 15% increased risk of falling in a year when overweight, which increases to 48% when BMI exceeds 40 $kg.m^{-2}$.[53] Foot size and shape is impacted alongside the rest of the body, with an increase in foot depth and width with increased BMI[7,54] and a greater contact area of the midfoot on the floor.[55,56] These differences is in morphology should be considered when designing footwear for this population.

Likely due to this increased size and reduced relative strength and stability, adults who are obese walk slower ($-0.14m.s^{-1}$) than their healthy weight counterparts.[57] Kinematics identify reduced cadence and stride length and increased stance width and double-support time.[51] The gait style apparent is obesity is less symmetrical and more variable than in healthy individuals.[58] Specific moderation to joint angles in gait are evident in lower extremity joints as well as postural differences at the trunk.[59] The ankle angle prolongs the first plantarflexion phase, there is an increase in adduction at the hip and a more everted heel,[51] faster eversion velocity and abducted forefoot position.[60] These are proposed as mechanisms to increase stability or as a direct consequence of larger thigh dimensions. The peak knee adduction angle is significantly higher throughout stance in individuals who are obese alongside a non-linear increase in ground reaction force and therefore the knee external adductor moment increases.[51] The altered physique and adapted gait apparent in individuals who are obese result in modified interaction of the wearer with their footwear, placing greater demand on specific features of the shoe when compared to adults of a healthy body mass. For example repeatedly loading the midsole with significantly higher forces and expanding the uppers beyond their anticipated volume leading to premature damage or deformation of the shoe, which in-turn may cause discomfort and further compromise gait of the wearer. Eliminating this mismatch between the footwear and wearer requires modified designs to account for both gait style and anthropometry.

In addition to the holistic health issues associated with obesity, 51% of people who are obese rate their foot health as fair/poor compared to 21% of patients with a healthy BMI.[45] There are significant negative correlations between BMI and foot pain, foot function, footwear satisfaction and general foot health.[61] Venous-insufficiency due to an elevated blood pressure and vascular resistance are associated with obesity, which can cause symptoms such as localised swelling in the lower limb, skin ulceration and sensations such as aching, heaviness, itching and pain. Oedema is associated with obesity, leading to reductions in tissue perfusion, swelling and discomfort in addition to posing risks of infection by acting as a site for growth of micro-organisms. These potential features of the foot of a person who is obese place requirements for permeable footwear materials, antimicrobial or washable properties or components and plus-size and/or adjustable footwear. The presence of obesity also increases the prevalence of overuse problems in the bone and soft tissue such as heel pain and plantar fasciitis (x1.4), tendinitis (x1.9) and osteoarthritis (x1.5) in the lower limbs compared to people of a healthy weight.[62] As aforementioned, loading at the medial compartment of the knee increases, resulting in a high prevalence of knee osteoarthritis in this population.[51] Structural changes to the foot arch due to excessive body mass also increase loading in the medial mid-foot and metatarsal heads, which can cause discomfort.[55] Footwear modifications or insoles are therefore related to off-loading localised pressures and providing shock absorption and "motion control".

Both the anthropometry and symptoms of obesity demand specific attributes from footwear. It is not unexpected that comfortable and appropriate footwear are perceived as more difficult to find as BMI increases and that people who are obese are unsatisfied with footwear currently available.[61,63] Solutions currently available generally increase the volume of the footwear upper and the contact area of the midsole. Unstable footwear has also been demonstrated to increase metabolic demand in people who are obese, however the efficacy of unstable footwear in an already unstable population requires further assessment.[64] The in-shoe environment and management of dermatological conditions through directed hosiery and footwear choices in addition to self-management should be a factor for the provision of footcare and footwear to obese adults. Consideration for the footwear upper and fastening is also key; a person who is obese may be unable to reach their foot and therefore slip-on footwear may be a consumer preference.

Conclusion

A full definition of the specific user needs within the target population is essential in order to provide the footwear technologists with information to design and manufacture footwear for these users. The needs of people who are older, people with diabetes and people who are obese vary from each other and the general population with regard to fit and footwear style considerations. Some needs, such as stable footwear, however, span all population groups, which can be achieved through similar technologies and considerations for all users. Convincing consumers to invest in footwear because of their foot health requires clear communication of the benefits the footwear can offer. The foot health problems are already well understood by professionals and are becoming increasingly better understood by consumers. Combining appealing aesthetic and trend qualities with functional performance is key to encourage adherence to footwear devices particularly. A benefits driven approach relies upon an educated consumer base, built up through a foot health education push from the health care sector and a complementary pull from the retail. This is a challenging area with so many public health messages now appearing for people to absorb and prioritise. However, acknowledging a foot health problem in the first place, is an essential foundation for consumer intention to purchase and, if products more clearly deliver benefits that align with the consumers' perceived problems, then sales should be more achievable.

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