Int J Diabetes & Metab (2010) 18:1-4

Foot Biomechanics for the treatment and prevention of diabetic foot ulcers

BC Whitt, G Steel, SM Rajbhandari
Lancashire Teaching Hospital, Preston Road, Chorley PR7 1PP, Lancashire, England, United Kingdom

Abstract
Abnormal pressure plays an important role in the pathogenesis of diabetic foot ulcers (DFU). Failure to relieve pressure is one of the most important reasons for non-healing of DFU. Adequate pressure relief is important both for the healing of ulcers and even after healing to prevent recurrence. There are various ways abnormal pressure can be distributed both to promote healing and also to prevent recurrance. In this article we review recent advances in redistributing pressure from foot that had developed DFU secondary to abnormal pressure from deformity due to Charcot neuroarthropathy.

Key Words: *Diabetic foot, biomechanic, orthotic, shoe, foot pressure*

Case History

FC, a 49 year old maintenance worker presented to his GP with hard skin over his right great toe which started to bleed. An ulcer was detected underneath it without him being aware of it. Fasting blood glucose of 7.4 mmol/l that was reconfirmed at a later date substantiated the diagnosis of Type 2 diabetes. His ulcer healed with regular treatment, however after 3 years he developed another ulcer on the plantar aspect of the interphalangeal joint of his right great toe. FC was assessed in the multi-disciplinary foot clinic and was diagnosed as a neuropathic foot ulcer. This was treated with total contact cast that healed the ulcer. FC's condition was further complicated when he presented 2 years later with a swollen, painful left foot. A bone scan confirmed the suspected diagnosis of acute Charcot neuroarthropathy (CN) and he was treated initially with a total contact cast followed by an Air cast walker. Unfortunately, due to prolonged absence from his job he was made redundant. Over the next few years his left foot developed some deformity (Figure 1) despite all effort to prevent it. FC's biomechanical management involved a close liaison with an orthotist who assessed his feet regularly and provided suitable footwear. This has accommodated his deformities and helped off-load pressure from sites of vulnerability and he has remained ulcer free most of the time.

Fig 1: FC's foot deformity due to Charcot neuroarthropathy. Note the bony prominence in the left foot with tendency of foot eversion giving increased load to medial side of the foot.

Fig 2: The stance phase of the gait cycle. During contact phase hindfoot strikes the ground. During midstance whole foot is in contact and during propulsuion forefoot is taking the load of whole body.

Introduction

Diabetes Mellitus is estimated to affect 246 million people worldwide[1] and 10-15% of these subjects will develop diabetic foot problem at some stage in their life.[2] In a recent survey, around 2.8% of all diabetic subjects had diabetic foot problems.[3] Non-traumatic lower limb amputation is 86 times more common in subject with diabetes than age matched general population [4] and almost all of them are due to diabetic foot problems. Therefore, a considerable amount of resource has been, and will continue to be placed on the prevention and treatment of the diabetic foot ulcers.

Abnormal pressure plays an important part in the patho-

Received on: 27/9/2009
Accepted on 3/3/2010
Correspondence to: Dr S M Rajbhandari, Lancashire Teaching Hospital, Preston Road,Chorley PR7 1PP, England, UK. E-mail: satyan.rajbhandari@lthtr.nhs.uk,

genesis of DFU. Failure to relieve pressure is one of the most important reasons for non-healing of DFU. FC weighed 98 kg and wore size 10 shoes with a surface area of 130 square cm. Therefore, on standing he was exerting 0.75 kg/square cm of pressure in his feet. When he walked the weight would pass through various part of the foot as per gait cycle.[5] The gait cycle is a complex, coordinated series of movements, but can generally be divided into 2 components: the stance phase (60%) and the swing phase (40%). It is the stance phase, when the foot is in contact with the ground, that is of particular interest with regard to diabetic foot.

The stance phase consists of 3 parts; (Figure 2)

Contact phase	the hind foot strikes the ground
Mid-stance phase	full forefoot loading to heel lift
Propulsion phase	maximum forefoot loading

Ground reaction forces (GRFs) act on the foot when exposed to the ground. These are vertical (absoloute) and horizontal (shear stress parallel to the foot skin). The GRFs peak during initial contact and forefoot loading when the surface area of the foot in contact with the ground is reduced. Therefore the highest plantar pressures are observed during the initial contact and propulsion phases.

Fig 3: FC's Charcot neuroarthropathy showing evidence of abnormal pressure secondary to deformity. Note callus which has been debrided and a small superficial ulcer underneath the callus over the great toe which healed within two a weeks.

Fig 4: Custom made shoes to accommodate FC's feet. Note the seamless nature of the shoes with increased width and depth.

Fig 5: Custom made insoles with increased areas of thickness to offload pressure. Note the medial arch support on left foot to prevent eversion of the left foot.

Fig 6: Note the fitted rocker on the left shoe to reduce plantar pressure on that side. The left shoe also has elevation at the medial side externally to prevent eversion.

Unfortunately, due to deformity caused by Charcot neuroarthropathy,[6] FC had abnormal pressure areas on the plantar surface of the foot mainly on the mid plantar surface and the great toe which took most of the pressure during gait cycle (Figure 3). Therefore, during walking the pressure exceeded 5 kg/square cm which exposed him to the risk of ulceration. This has been prevented by regular debridement of the callus and specialist orthotic foot wear. Studies have shown that despite successful healing of diabetic foot ulcers the recurrence can be as high as 30% in one year.[7]

Assessment of Pressure

The most important assessment for pressure is clincal examination of the foot and the shoe patient is wearing. Clinical examination should involve inspection for ulcers and presence of deformity, palpation of pulses and examination for neuropathy using 10 gm filament. It is very important to look for the presence of callus which are the signs of abnormal pressure and are precursor to ulcer. Table 1 shows what should be assessed in this examination.

Table 1: A biomechanical assessment of the diabetic foot

Foot type	flat/pronated rectus/straight cavus/high arched
Deformities	Charcot neuroarthropathy hammer/claw toes hallux vulgus prominent metatarsal heads presence of callus
Range of motion	dorsiflexion and plantarflexion inversion or eversion length, width and arches
Current footwear	flattened insoles tight/loose shoes shoes leaning to any side

Although the objective measurement of foot pressure is extremely useful, it is not feasible in day to day clinical practice due to time and expense. There are various systems available for measurement of pressure such as F scan.[8] This requires trained personnel and gait laboratory. The measurement may be useful in designing shoes in complex cases but is not recommended for routine clinical use.

Treatment

Having assessed the foot, it is important to releive pressure in order for ulcer to heal and prevent future ulcerations.

If there is ulcer

The benefit of removing pressure from a neuropathic foot ulcer (i.e., reducing mechanical stress, or off-loading) is well established.[9] Techniques for removing pressure include the use of total contact cast, Aircast pneumatic walker, DH pressure relief walker, depth-inlay shoes, half shoes, sandals etc. Total contact cast (TCC) is a safe and effective way of off-loading the ulcer and is considered to be the standard treatment for neuropathic ulcers.[10] FC had been treated with total contact cast when he developed neuropathic foot ulcer and that healed within 4 weeks.

When there is no ulcer

Once the ulcer was healed in FC's case, it was important to relieve pressure to prevent recurrence of ulcer. It is important to note that pressure can only be redistributed, never removed. Therefore, the primary objectives of pressure treatment is to redistribution it by devices in order:

- To provide cushioning by reducing shock and shear
- To accommodate the foot by redistributing plantar pressure to below the level of the threshold of ulceration
- To realign mechanically imbalanced structures
- To stabilize or unload rigid or deformed structures

Footwear

In a recent study it was found that 83% of diabetic subjects did not wear appropriate footwear.[11] In subjects with foot problem extra-depth shoes are the mainstay of prescribed footwear and are designed with two main purposes; to have sufficient space to allow a simple or specialized insole to be placed, and to have space to ensure that the dorsum of toes are not pushed against the upper of the shoe. This accommodates for plantar deformities and dorsal deformities respectively. They are made of soft leather, are generally seamless, wide and deep with a large toe box. Shoes should be well fitting and have laces or velcro strap so that various parts of the foot are held at appropriate sites. There may be a need to modify shoes from the outside to accommodate severe deformities. Similarly, there may be a need for above ankle boot to stabilize ankle joint and to hold foot deformities in its designated space. FC has been supplied with such pair of shoes which accommodates his deformity of the left foot (Figure 4).

Insoles

It is important to mention *simple insoles* as a mechanism of cushioning, absorbing shock and reducing shear. However, they are often inadequate for the needs of the very high-risk foot with severe deformity as they do not redistribute force and can 'bottom out' with use. *Total Contact Insole (TCI)* is a long term and practical method of mechanical management and can achieve the objectives stated above. It is custom-moulded according to the plantar morphology of the patients foot using phenolic foam to create a foot impression from which a custom made insole is made.[12] TCI's can also be used in ordinary shoes, healing sandals and removable cast walkers. FC had been supplied with TCI as a measure to redistribute the pressure and to reduce shear strain on walking (Figure 5).

Modification of soles

Most often, no modification of soles is needed. However there may be a need of rocker soles. These are designed to spread fore foot loading pressures over the entire plantar surface. The rocker is positioned to reduce ground reaction force at areas of high pressure by moving the centre of pressure proximal to a high pressure site. This modification also aims to speed the heel to toe progression during the gait cycle. Modified temporal sequencing reduces the time that forces act on any area of the foot. Similarly, Metatarsal pads and bars can be used either inside the shoes or outside. This can provide load relief at a bony prominence. Their exact location is critical to their effectiveness and so prescription can be difficult. It has been shown that a 5 mm difference in positioning can markedly affect the load relief provided.[13] FC had significant deformity due to Charcot neuroarthropathy on the left side with a high pressure area over the mid foot so a rocker was provide in that side (Figure 6).

Surgery

Surgical treatment can be minor one such as debridement of callus to major operation to correct deformity. Callus formation occurs as a result of tissue damage to areas exposed to repeated pressure. These are superficial hard areas of skin often overlying an ulcer. Haemmorhage into the callus indicates a 'preulcerative' lesion. An observational study reported that the increased risk of ulceration in an insenstitive foot with a callus was 77-fold.[14] Regular debridement of callus could reduce plantar pressure and reduce ulceration.

The therapuetic use of liquid silicone injections in the foot has been suggested to improve cushioning at callus sites and localized painful areas. A placebo controlled trial showed that this decreased peak plantar pressure and callus formation and increased plantar tissue thickness.[15] It can be seen that the cushioning effect is still significant at 1 year following the injections, but at 2 years follow up the cushioning properties reduce suggesting that regular injections may be required. It would seem likely that these results would help prevent the risk of foot ulceration, although this needs to be confirmed in further trials.

Achilles tendon lengthening is a procedure to increase ankle dorsiflexion which is thought to help decrease forefoot plantar pressure, hence reducing ulcer formation. Many trials have shown this to have a positive effect. One such study evaluated dynamic pressures on the forefoot of 10 diabetic patients known to be at risk of ulceration due to previous ulcers. Analysis of the data before surgery and 8 weeks after showed that mean peak pressure on the plantar aspect of the forefoot decreased from 86 kPa to 63 kPa.[16]

Metatarsal head resection has shown numerous positive outcomes in altering bone deformity of the rheumatoid foot, but there has been little evidence to show that this improves the prognosis of the diabetic foot. However, one study analysed plantar pressure distribution of 16 diabetic patients before and after surgery and concluded that there could be scope for such a technique in diabetic foot management.[17]

Charcot foot reconstruction surgery can have a role in the management of chronic CN if there is a marked instability, fixed deformity or a recurrent ulcer. Internal fixation shows positive results but can have complications such as infection and vascular insult. More recently, external fixation has been shown to provide rigid immobilization and normal weight bearing stress with reduced soft tissue dissection.[18]

Conclusion

It is known that abnormal pressure plays a crucial role in the development of an ulcer. However, it is not clear about the relative contribution of different aspects of biomechanics such as direct pressure, shear stress, activity volume and patient compliance. An 'active' person takes on average 10,000 steps per day which give substantial stress to the feet.[19] An understanding of foot biomechanics is essential to the clinicians involved in diabetic foot management, and if rates of amputation are to be reduced then biomechanical intervention inevitably needs to be implemented for a patient to gain maximum benefit. FC had active biomechanical management which had an extremely positive effect on the health of his foot.

References

1. IDF. Diabetes Atlas http://www.eatlas.idf.org/media, 2006.
2. Palumbo PJ, Melton LJ. Peripheral vascular disease and diabetes. In: Harris MI, Hamman RF (eds), Diabetes in America, NIH Pub 1985; No, 85-1468, pp. XV 1-21. Washington: US Government Printing Office.
3. Sämann A, Tajiyeva O, Müller N, Tschauner T, Hoyer H, Wolf G, et al. Prevalence of the diabetic foot syndrome at the primary care level in Germany: a cross-sectional study. Diabet Med 2008; 25:557-563.
4. Jonasson JM, Ye W, Sparén P, Apelqvist J, Nyrén O, Brismar K. Risks of nontraumatic lower-extremity amputations in patients with type 1 diabetes: a population-based cohort study in Sweden. Diabetes Care 2008; 31:1536-1540.
5. http://www.gp-training.net/rheum/gait/gait.htm
6. Rajbhandari SM, Jenkins RC, Davies C, Tesfaye S. Charcot neuroathropathy in diabetes mellitus. Diabetologia 2002; 45:1085-1086.
7. Lavery LA, Higgins KR, Lanctot DR, Constantinides GP, Zamorano RG, Athanasiou KA, et al. Preventing diabetic foot ulcer recurrence in high-risk patients. Use of temperature monitoring as a self-assessment tool Diabetes Care 2007; 30:14-20.
8. http://www.tekscan.com/medical/system-fscan1.html
9. Boulton AJM, Kirsner RS, Vileikyte L. Neuropathic Diabetic Foot Ulcers. NEJM 2004; 351: 48
10. Hunt D. Foot ulcers and amputations in diabetes. Clinical Evidence 2005; 13: 1-2
11. Harrison SJ, Cochrane L, Abboud RJ, Leese GP. Do patients with diabetes wear shoes of the correct size? Int J Clin Pract 2007; 61:1900-1904.
12. Janisse DJ. Prescription insoles and footwear. Clin Podiatr Med Surg 1995;12:41-61.
13. Hayda R, Tremaine K, Banco S, Teed K. Effect of metatarsal pads and their positioning: a quantitative assessment. Foot Ankle Int 1994; 15:561-566.
14. Frykberg RG, Lavery LA, Pham H, Harvey C, Harkless L, Veves A. Role of neuropathy and high foot pressures in diabetic foot ulceration. Diabetes Care 1998; 21: 1714-1719.
15. van Schie CHM. A Review of the Biomechanics of the Diabetic Foot. Int J Low Extrem Wounds 2005; 4:160
16. Armstrong DG, Stacpoole-Shea S, Nguyen H, Harkless LB. Lengthening of the Achilles tendon in individuals who are at high risk for ulceration of the foot. J Bone Joint Surg Am 1998; 81: 53553-53558.
17. Patel VG, Wieman TJ. Effect of metatarsal head resection for diabetic foot ulcers on the dynamic plantar pressure distribution. Am J Surg 1994; 167:297-301.
18. Sayner LR, Rosenblum BI. External fixation for Charcot foot reconstruction. 2005; Curr Surg. 2005 62:618-623.
19. Lavery LA, Armstrong DG, Vela SA, Fleischli JG. Practical criteria for screening patients at high risk for diabetic foot ulceration. Arch Intern Med 1998; 158:157-162