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Wound Measurement in Diabetic Foot Ulceration

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1. Introduction

In this chapter the authors aim to provide a brief introduction to wound assessment in the diabetic foot and discuss the role of wound measurement within that assessment process. A literature review describing wound measurement in diabetic foot wounds was conducted and a review of wound measurement tools and techniques reported. The results of a wound measurement study using a particular technique and the importance of wound measurement in clinical practice is discussed. Conclusions are drawn and a way forward is suggested.

The prevalence of diabetes worldwide was estimated to be 2.8% in 2000 rising to 4.4% in 2030. The total number of people with diabetes is projected to rise from 171 million in 2000 to 366 million in 2030 (Wilde et al, 2004). As diabetes is the most frequent cause of non-traumatic amputation in the developed world, it is likely that there will be a significant impact on patients' health, their carers and health care systems. Progress has been made in recent years to manage risk factors associated with diabetic foot ulceration and to manage infection, ischaemia and glycaemic control. Multidisciplinary assessment, treatment and education programmes have been developed to prevent damage to insensitive feet. Healing rates and outcomes related to diabetic foot ulceration have been studied by many investigators and various wound measurement techniques have been employed in the quest to quantify outcomes. Outcomes in terms of ulcer healing have been based on ulcer area, ulcer duration and ulcer grade (from the superficial abrasion to the ulcer presenting with exposed bone in the wound base, necrosis, infection and/ or osteomyelitis). Initial wound measurement and regular monitoring is a useful tool in the assessment of treatment effectiveness (Vowden and Vowden, 2005, Gethin, 2006).

2. Wound assessment and the role of wound measurement

Wound assessment is complex and multi-faceted. It includes wound appearance, wound aetiology, prediction and monitoring of healing rates, identification of factors delaying healing and wound documentation. Wound measurement is an important component of this and has the potential to provide baseline measurements and accurately determine the percentage reduction/increase in wound area over time.

In any study involving wound measurement there are key concepts to be considered:

1. Accuracy. This is the ability of the measuring tool to measure the true size of an object.
2. Validity. The ability of the measuring tool to measure what it is intended to measure.
3. Repeatability/test-retest reliability. The ability of the measuring tool to repeat an accurate measurement on more than one occasion with consistency.
4. Reliability and Inter-rater reliability. The consistency of results obtained using the device when used by one or more than one operator.
5. Usability. Do users find the tool convenient, effective and easy to use? (Fette, 2006).

For a measurement tool to be successful it must satisfy these criteria and demonstrate reliability in its application. Failure to do so will result in inappropriate data. In the case of wound measurement systems the most common means of assessing the reliability of a system are test-retest reliability and inter-rater reliability (Gilman, 1990).

Ideally the outcome of any treatment regimen in the management of diabetic foot wounds is complete wound closure. It has been suggested that the ability to measure a percentage area reduction may be important in differentiating between healing and non-healing wounds, and that it is also important for the evaluation of the efficacy of different treatment regimens ((Kantor and Margolis, 2000; Flanagan, 2003; Sheehan et al, 2003; Gethin, 2006; Papazoglou et al, 2010). In wound management, three types of outcome are important: therapeutic efficacy, value for money and patient satisfaction (Gallagher, 2003). Oyibo et al (2001) in a study of diabetic foot ulcers (n=194) investigated the effect of ulcer size and site, patients' age, sex and type/duration of diabetes on the eventual outcome. They found that ulcer area correlated well with healing time, but age, sex, type and duration of diabetes did not affect outcome. They concluded that ulcer area could be a useful predictor of ulcer outcome. This is supported by the work of several authors who concluded that percentage change in ulcer area at 4 weeks was a robust predictor of healing in diabetic foot wounds (Flanagan, 2003; Sheehan et al, 2003; Gethin, 2006; Papazoglou et al, 2010).

3. Wound measurement tools and techniques

A broad search of the literature was conducted to identify search terms and filters that could be used to yield studies specific to wound measurement tools and techniques in wound healing overall and more specifically in diabetic foot wounds. The electronic databases used to identify papers relevant to this review were Pubmed, Medline, and Cinahl (1989-2011). Secondary hand searching was also carried out using relevant journal articles and reference lists, books, and conference proceedings. Papers were included if they reported on trials describing and comparing wound measurement methods and tools. Papers were excluded if they were not written in English.

Quantifying the size of the wound is an important component of wound assessment and has the potential to provide baseline measurements and accurately determine the percentage reduction/increase in wound area over time (Flanagan, 2003; Margolis et al, 2003). There are many methods of wound measurement and each possesses advantages and disadvantages. The ideal tool has been described by Polit & Hungler (1995) as

“one that gives rise to results that are relevant, accurate, unbiased, sensitive, uni-dimensional and efficient”.

Wound measurement techniques can be categorised as contact or non-contact in their application. Contact techniques include acetate tracing of the wound, the use of depth gauges, and volume measurement using casts or saline. Non-contact techniques involve the use of structured light and lasers, photography, video image analysis, magnetic resonance imaging and stereophotogrammetry (Williams, 1997). These tools and techniques are described, discussed and compared in detail.

3.1 Simple wound measurement

Simple wound measurement methods include those techniques that use either a length and width measurement or a wound tracing to calculate surface wound area. To determine wound surface area there are two important issues: the identification of the wound margin (typically using a wound tracing or alternatively a digital image) and the calculation of wound area.

It is essential that the wound margin is clearly identified prior to measurement regardless of the measurement tool used. The appearance of the wound may be affected by various factors all of which may influence accurate measurement:

1. Haemorrhage following debridement.
2. The presence of infection and undermining of the wound edges.
3. The presence of excess wound exudate and evidence of maceration of the surrounding skin.

The wound edge may be described clinically as the area where normal skin converts to tissue which is red, yellow or black in colour. Normal skin may be macerated and white in appearance, or there may be lilac coloured tissue (new epithelial tissue) at the leading edge of the wound.

Identification of the wound edge may be difficult and is largely determined by the subjective assessment of the observer who performs the measurement (Plassmann & Jones, 1992; Plassmann et al, 1994; Plassmann, 1995).

Current practice focuses on wound measurement using a simple length and width measurement to calculate surface wound area. This is a crude measurement. Surface wound area is calculated by multiplying the maximum perpendicular length by the maximum width of the wound bed and is typically recorded in cm² (Flanagan, 2003). The major flaw in the method is that it is subjective and normally over-estimates wound area by approximately twenty five percent (Majeske, 1992; Dealey, 1994; Goldman and Salcido, 2002; Rodgers et al 2010). This method does not take into account irregularities in the shape of the wound or wound depth. Advantages, however, include ease of use and low cost.

Wound area can also be determined by tracing the outline of the wound (wound circumference) onto a transparent sheet or graph paper divided into 1cm squares. Wound area can then be calculated by manually counting the squares within the "wound". Griffin et al (1993) compared photographic and transparency-based methods for measuring wound area and concluded that both methods provided equally reliable measurements, but that the transparency method was more economical in time and equipment requirements. This is also a subjective measurement and the identification of the actual wound edges can be

difficult. The process does not provide information on the 3-dimensional aspect of the wound nor on wound volume and depth. It is also recognised that tracing of the wound edges is where the greatest source of error occurs (Kantor and Margolis, 1998). This is largely dependent on the experience of the clinician (Flanagan, 2003). The main advantage of wound tracing however is that it takes into account body curvature and irregularities of wound circumference.



Fig. 1. Photograph illustrating the various types of tissue used to identify the wound edge in a diabetic foot wound

3.2 Mathematical models

It is recognised that simple wound surface area measurements (length x width) are likely to over-estimate the area of the wound by approximately twenty five percent (Goldman and Salcido, 2002). Ruler based schemes tend to be less reliable in wounds $>5\text{cm}^2$ (Oien et al, 2002). Accuracy may be improved by tracing the wound to compensate for body curvature, but this can be difficult to perform in certain areas e.g. the heel. In 1989 Kundin developed the wound gauge to calculate wound area (wound length x width x 0.785) and wound volume (wound area x depth x 0.327). This method appeared to be accurate in the measurement of small wounds but consistently underestimated the size of larger or irregularly shaped wounds (Thomas and Wysocki, 1990).

Oien et al (2002) and Johnson (1995) proposed that various mathematical formulae can be used to improve accuracy in the calculation of wound surface area and volume. They recognised that most foot wounds presented as spherical or elliptical in nature, and that the area of these wounds could be determined using recognised standard mathematical

formulae and a wound tracing. This is also likely to produce some over-estimation of ulcer size but less error than the simple area calculation using length and width only (Goldman and Salcido, 2002).

The use of the elliptical method of wound measurement was described by Shaw et al (2007). In a study of measurement of diabetic foot ulcers, wounds were traced, measured with a ruler and the standard formula for the calculation of the area of an ellipse was applied. The surface area was calculated by taking the radius of the longest side of the ellipse (wound), multiplying it by the radius of the shortest side of the ellipse (wound), at 90° to the longest side and multiplying that value by π (where $\pi = 3.14$) and r is the radius measurement.

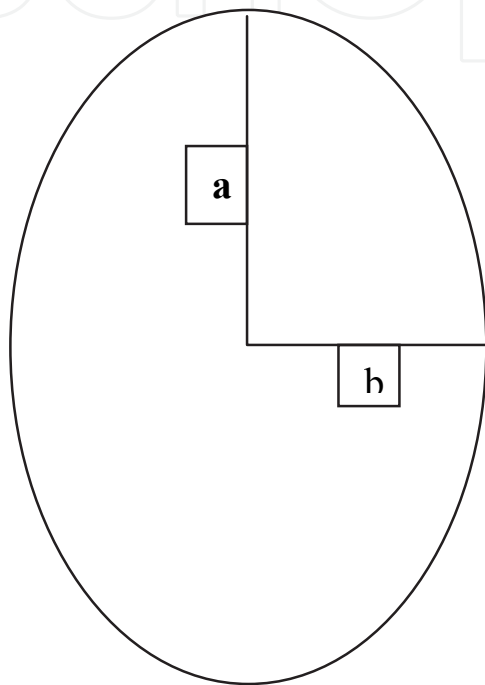


Fig. 2. The area (of the ellipse) is calculated using the formula πab

Johnson (1995) described various mathematical formulae to measure circular, elliptical and irregular wounds. He suggested that if wounds present with an irregular shape, 8 radii can be identified, each taken approximately 45° from the next radius and results can be approximated to actual values. The formulae to calculate the surface area is as follows:

$$(r_1^2 + r_2^2 + \dots + r_8^2)(\pi / 8)$$

3.3 Wound planimetry

Wound planimetry is defined as the precise measurement of the area contained within a wound tracing or a digital image (Flanagan, 2003). This measurement can be carried out using a mechanical planimeter or by using an appropriate software package and a digital image. Oien et al (2002) compared four methods of wound measurement in 20 patients with leg and foot ulcers (n=50) of mixed aetiology. Techniques included mechanical planimetry (using a hand held device), digital planimetry, square counting approximations and simple length x width measurements. All methods demonstrated a high degree of agreement for smaller wounds (<10cm²) but differences occurred as wound size increased. The simple

length x width measurement was reported to be the least reliable measure of ulcer size followed by square counting and mechanical planimetry. Digital planimetry was the most reliable of the methods described (Oien et al, 2002).

3.4 Stereophotogrammetry and light techniques

The availability of both contact and non contact methods of wound measurement have already been alluded to. Stereophotogrammetry is a non-contact technique where a stereo camera linked to a computer captures an image of the wound (Plassmann & Jones 1992; Langemo et al, 1998). The image is downloaded to the computer and the wound manually traced with the mouse from the image presented on the computer monitor screen. The software package then calculates wound length, width, area and volume. Langemo et al (1998) reported that the main advantage of this method was that it produced highly reproducible results compared to other techniques. It is also a non-contact technique, and so minimises the risk of cross-infection. The main disadvantage however is that it is time consuming both in terms of set-up and data collection (Plassmann and Jones, 1992).

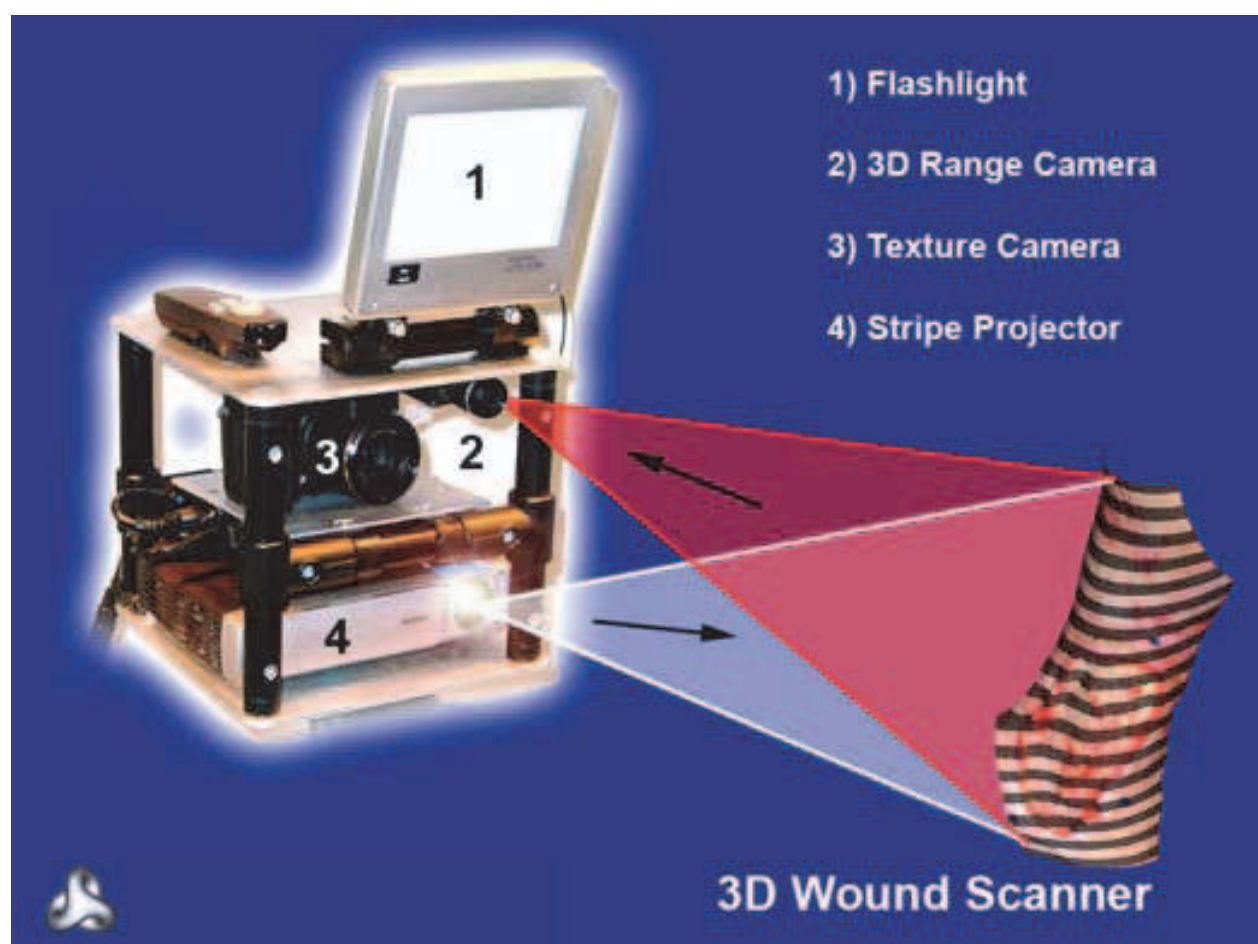


Fig. 3. Illustration of stereophotogrammetry.

A further non-contact method utilising light has been described by Plassmann and Jones, 1992; and Melhuish et al, 1994. This structured light triangulation method involves use of a beam of structured light aimed at 45° to the wound. Analysis of the image carried out by computer software provides a 3-dimensional map of the wound allowing accurate measurement of wound area, wound circumference and wound volume. Repeated measurements using this method reported results with a mean error of less than 5% and so it was deemed to be an accurate way of objectively determining the wound boundary and calculating wound area. Melhuish et al (1994) demonstrated a direct correlation between wound circumference and wound area, and wound circumference and wound volume. The authors suggested that it was possible to accurately monitor wound healing by measuring circumference alone, as this measurement was directly linked to both volume and area.

4. Comparison of techniques

None of the methods of wound measurement described is perfect. Clinicians are expected to provide high quality, cost-effective, evidence-based wound care and so the standardisation of wound measurement methods may have important implications for research into the effects of treatments, drugs and disease (Kundin, 1989).

4.1 Simple measurement

Mayrovitz (1997) investigated shape and area measurement in the assessment of diabetic plantar ulcers (n=83). The accuracy of area calculations based on elliptical and rectangular shapes was considered and based on the maximum length and maximum width of the wounds studied. Overall error for both methods was similar with the elliptical model overestimating area (by 10%), and the rectangular method underestimating the area (by 12%) when compared to conventional wound tracing over a sixteen week period. This is in contrast to the results reported by Majeske in 1992, and Goldman and Salcido (2002) who reported that wound area measurement using a simple length and width calculation overestimated wound area by approximately twenty five percent.

4.2 Mathematical models

Gilman (1999) favoured a more complex mathematical model for wound measurement. He argued that in many wound studies there were always wounds of varying sizes and shapes, and so a valid comparison of healing was difficult. He proposed using a mathematical model that described the average distance of advance of the wound margin towards the wound centre over time. This was illustrated in wounds that closed in a uniform and non-uniform way. Bowling et al (2009) reported a strong correlation between elliptical wound measurement and an image processing system in a series of 36 diabetic foot wounds, examined over a 12 week period.

4.3 Wound planimetry

Kantor and Margolis (1998) reported a good correlation between planimetric wound area and wound width, length, width x length, perimeter and area based on the formula for an ellipse. The values for all correlation coefficients were greater than 0.8 for wounds that were less than 40cm² in size.

4.4 Stereophotogrammetry and light techniques

In keeping with the work carried out by Mayrovitz (1997), Langemo et al (1998, 2001) compared linear length and width using several methods: a ruler, planimetry, computerised stereophotogrammetry (SPG) length and width and computerised SPG area. They found that the most reliable method was SPG area measurement followed by computerised planimetry. These authors noted that conventional length x width measurement produced the greatest variability in wound area measurement.

The above work was further supported by Lagan et al (2000), who compared the reliability of direct and photographic tracings analysed by planimetry and digital techniques in the measurement of various wound types. The level of repeatability of these methods and the level of variability in wound size was investigated. There was increased variability using planimetry compared to digital techniques and planimetry produced lower readings for wound measurement overall.

Shaw et al (2007) evaluated and compared three wound measurement techniques: the Visitrak system using acetate tracings and planimetry (Smyth and Nephew Healthcare, Hull UK), a digital photography and image processing system (Analyse, Version 6.0; Analyse Direct, Lenexa, KS) and a wound tracing and elliptical measurement method using the standard formula (πab) for the calculation of the area of an ellipse. These methods were used to measure wound surface area for a series of diabetic foot wounds (n=16), of greater than four weeks duration.

Validity within each measurement method was determined using a one-sample t test. Repeatability within each method was investigated by calculating a coefficient of variation (CV) for each wound measurement. An ANOVA was used to complete a calculation of comparability between the methods. A paired t- test was used to examine differences between the elliptical and Visitrak methods.

Validity varied across the three methods but was considered to be acceptable. The Visitrak method measured images <25mm² inaccurately and the elliptical method of measurement tended to underestimate size in small wounds. The image processing method was inaccurate for both large and small wounds. Repeatability was acceptable across the three methods. The mean CV for all wounds was calculated as 7.0 for Visitrak, 4.7 for image processing, and 8.5 for the elliptical method. No one method was more repeatable than another. An analysis of comparability between the methods indicated variability particularly between the Visitrak and elliptical methods. The main limitations of the study are that the sample size was small and conclusions can only be drawn for diabetic foot wounds.

5. Implications for clinical practice

Ideally the outcome of any treatment regimen in the management of diabetic foot wounds is complete wound closure. The ability to measure a percentage area reduction may be important in differentiating between healing and non-healing wounds, and for the evaluation of the efficacy of different treatment regimens. Several authors have described the importance of regular wound measurement and reported that a percentage change in wound area over a 4 week period of 30% or more, reliably predicted wound healing (Kantor and Margolis, 2000; Sheehan et al, 2003; Gethin, 2006; Papazoglou et al, 2010).

6. Discussion

Historically wound measurement techniques have focussed on 2-dimensional methods using linear measurement, wound tracings and photography for wound assessment in the clinical setting (Langemo et al, 1998). To date there is still no standardised, universally accepted method with the method chosen largely depending on the level of accuracy required. If a broad indication of wound size is required then a simple technique that is minimally invasive, fast and comfortable for the patient may be adequate. If a more accurate measurement is required (for example in a research study or to enable clinicians to predict wound healing), a more robust method is necessary. Any wound measurement technique has to demonstrate that it is accurate, repeatable and capable of influencing patient care in a positive, cost-effective manner. This can be aided when used in conjunction with a wound measurement protocol (Plassmann and Peters, 2001). Clinicians will inevitably be influenced by the ease of use of a particular tool and efficient use of clinical time.

Simple ruler-based methods provide a crude wound measurement that overestimates wound area by twenty five percent. Complex mathematical models may not be useful for busy clinicians unless incorporated into appropriate software packages that are quick and easy to use. However simple formulae such as those discussed earlier to calculate the area of an ellipse can be used easily in conjunction with wound tracings. The main advantages of this method were that it was quick, easy to use, and non-invasive and that it considered body curvature. Limitations of this method are recognised in that there may be an overestimation of wound area by around 10% (Mayrovitz, 1997). However, diabetic foot wounds are often spherical or elliptical in nature, and Shaw et al (2007) have shown that this is a valid and repeatable method of measurement to use in this group of patients. In contrast in this study, the elliptical method was shown to underestimate wound size compared to tracing and planimetry (Visitrak system) and an image processing system.

Wound planimetry can be carried out within a wound tracing or a digital image. Measurement of wound area is reported to be most accurate in smaller wounds $<10\text{cm}^2$. The main advantages of the Visitrak method was that it was quick, easy to use, non-invasive, it considered body curvature and the subjectivity of manually counting squares was removed. The main disadvantage was that it tended to underestimate wound size compared to the elliptical method and was inaccurate in the measurement of wounds $<25\text{mm}^2$ (Shaw et al, 2007).

Digital imaging takes considerable time and studies seldom show the total time to capture the image, transfer the image from the camera to the computer, and then calibrate and measure the wound. Computerised methods may be more accurate, but their use is limited due to availability, complicated calibration procedures, cost and clinician time (Plassmann and Jones, 1992; Xiang Liu et al 2006). The advantages of digital imaging are that it facilitates unique calibration at each wound measurement and subjective wound tracing is eliminated. However the accuracy of results does depend on the investigator's ability to take a high quality image in the first instance and the accurate identification of the wound edge from the image. Many additional factors also require management such as lighting, environment and the distance of the camera from the foot. This method clearly has great potential, but depends largely on the clinicians' ability to identify the wound margin accurately, as well as the influence of practical factors in the clinical environment.

7. Conclusions and the way forward

Various methods of wound surface area measurement have been described, and the advantages and disadvantages of each have been discussed. It is essential that an appropriate method is chosen if diabetic foot wounds are to be measured accurately as well as to provide robust results in research wound healing studies.

Historically wound measurement techniques have focussed on 2-dimensional methods using linear measurement, wound tracings and photography for wound assessment in the clinical setting. To date there is still no standardised, universally accepted method used. Digital imaging and computerised methods take considerable time and can be costly and complex mathematical models may not be useful for busy clinicians unless incorporated into appropriate software packages that are quick and easy to use. Computer software that automatically identifies the wound edge thus increasing accuracy and speed of measurement would be a major step forward.

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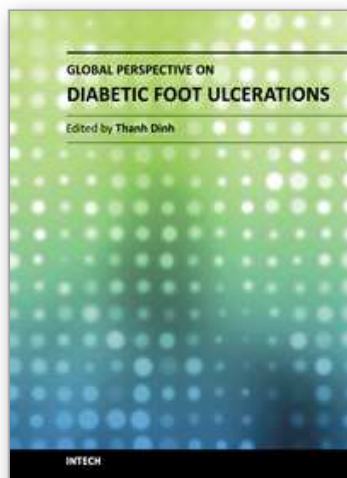
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Global Perspective on Diabetic Foot Ulcerations

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Over the last decade, it is becoming increasingly clear that diabetes mellitus is a global epidemic. The influence of diabetes is most readily apparent in its manifestation in foot complications across cultures and continents. In this unique collaboration of global specialists, we examine the explosion of foot disease in locations that must quickly grapple with both mobilizing medical expertise and shaping public policy to best prevent and treat these serious complications. In other areas of the world where diabetic foot complications have unfortunately been all too common, diagnostic testing and advanced treatments have been developed in response. The bulk of this book is devoted to examining the newest developments in basic and clinical research on the diabetic foot. It is hoped that as our understanding of the pathophysiologic process expands, the devastating impact of diabetic foot complications can be minimized on a global scale.

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