Chapter 1
Introduction

Historical introduction
To understand contemporary clinical gait analysis it is useful to briefly review its history (Baker 2007). At least since the time of Aristotle (384–322BC) walking has fascinated scientists. Through the Renaissance and Enlightenment there became an increasing appreciation that human movement is regulated by the same underlying principles that govern the movement of inanimate objects, and the field of biomechanics began to emerge. Until the middle of the 19th century there was no way to record human movement, and most of the understanding of walking was essentially conjecture. The advent of photography, however, presented a means of making such measurements and allowed the first genuinely scientific attempts to understand walking. Pioneering work by Muybridge (1830–1904) and Marey (1830–1904) came to full fruition in the remarkable achievements of Braune (1831–1892) and Fischer (1861–1917) just before the turn of the 20th century.

The need to rehabilitate amputees returning from war stimulated both Amar (1879–1935) and Inman (1905–1980) to apply the new techniques to study walking in disabled populations and develop the first clinical research programmes to use movement analysis techniques. Reliance on laborious processes for both making measurements and processing data effectively prevented the application of the new techniques to the assessment of individual patients. The first such technique to become clinically practical was electromyography (EMG) and this was adopted by the early pioneers of clinical gait analysis, Perry (1918–2013), Sutherland (1923–2006) and Baumann (1926–2000). All three found it difficult to interpret the results without some understanding of how the patient was moving however. Perry developed semi-objective observational scales whilst Sutherland and Baumann developed movie-based techniques. Sutherland pushed further and started to develop techniques to abstract kinematic
variables from cine film. Without automated data capture, however, these remained impractical in a clinical context.

The breakthrough came with the development of the video camera and of computers capable of processing the data that these produced. James Gage drove the team that pioneered the application of this new technology and opened the first modern clinical gait analysis service at the Newington Children’s Hospital, Connecticut, USA in 1981. At around the same time several systems became commercially available and a number of hospitals in North America and Europe started developing similar services. It was not long before systems started incorporating force plate data and EMG recordings with the kinematic data extracted from the video signal.

Through the rest of the 20th century a broad consensus developed among this small group of clinical services on how to perform a clinical gait analysis. This tradition might appropriately be called conventional clinical gait analysis. Gage’s commitment to promote clinical gait analysis and develop training and education packages was an important driver of this as was the rather inflexible VICON Clinical Manager software developed by a major commercial supplier of gait analysis systems. As the technology became more widely available in the early years of this century a large number of hospitals developed services using systems from a variety of suppliers with software that could be used more flexibly. A large number of sources for training and education have also been developed. The result is that whilst there is still a considerable degree of uniformity among the older, more established services, particularly in the US and UK, there is also considerable variability as to how clinical gait analysis is implemented amongst many of the newer services. Whilst there is much to be gained by experimenting with new approaches, constructive progress is most likely to be made by doing so within a thorough understanding of the conventional approach. The primary aim of this book is to provide an understanding at a level that gives clear guidance on how clinical gait analysis services can be delivered within this tradition.

What is clinical gait analysis?
Many of us involved in this field are so familiar with the use of complex measurement systems that we forget that for the vast majority of clinicians gait analysis is an observational process. This book, however, is essentially about instrumented gait analysis. Hereafter the term instrumented has been dropped simply because it is too cumbersome to be used repeatedly. There is a chapter on how to take a clinical video but the use of this is discussed primarily in relation to how this supplements data from more complex systems.

Many of the centres in which clinical gait analysis services were pioneered ran highly integrated services, typically in paediatric orthopaedics, in which the gait analysis was just one component. In these the boundary between performing a clinical gait analysis and treating the patient was often blurred or even non-existent. In other places the gait analysis is much more clearly delineated from clinical decision-making with one group
of professionals performing the assessments and another making the decisions. Different models of service provision lead to different understandings of what clinical gait analysis actually is.

This book will assume that gait analysis is the process of determining what is causing patients to walk the way they do. This is based on instrumented measurement (which is an objective process) and a biomechanical interpretation of what these measurements mean (which still requires some subjectivity). Whilst this process can be used to inform clinical decision-making, it is possible to make a clear distinction from it. Gait analysis is sometimes referred to as diagnostic, but there are very few conditions in which gait analysis actually contributes significantly to the diagnosis. It is perhaps preferable to consider it as an assessment process.

The distinction between assessment and decision-making is important because gait analysis has come in for significant criticism over the years. As typified by Wright (2003), this has two strands. The first is that there is unacceptable measurement variability. This was a justifiable criticism 10 years ago (Noonan et al. 2003) but more recent work suggests that with appropriate quality assurance procedures acceptable measurement error is achievable (McGinley et al. 2009). The second is that gait analysis results in ‘widely divergent treatment recommendations’. This is not a valid criticism of the clinical gait analysis as defined in the paragraph above. Two surgeons looking at the same radiograph will choose to manage a fracture differently. Their choice will depend on their personal experience and expertise and what facilities are available to them. The fact that they make different decisions does not make us question whether they should have used that radiograph as part of the decision-making process. Indeed, there is an expectation that they should use whatever data is available and relevant to guide their clinical practice.

The distinction between assessment and decision-making is also important for ensuring excellence in service provision. Making reliable measurements in gait analysis and providing rigorous biomechanical interpretation is extremely difficult. Both these processes require high levels of knowledge and expertise. It will be a very rare person who can provide these and the similar levels of knowledge and expertise that are required for clinical decision-making and patient management. Acceptable levels of clinical performance of gait analysis will only come through maintaining a focus on the gait analysis process itself. This can be a considerable challenge in centres in which the patient assessment, clinical decision-making and patient management are integrated. In these situations it is probably even more important to maintain a conceptual distinction between the assessment and decision-making processes than in centres where the two roles are organisationally and/or physically separate.

The distinction is also important when deciding who should staff gait analysis facilities and how they should be trained. The historical blurring of the assessment process, clinical decision-making and patient management in the pioneering centres led to the assumption that gait analysis should be delivered by the existing clinical staff (generally physiotherapists) with some additional training. Measurement theory
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and biomechanics are, however, not generally taught rigorously in clinical training programmes (core skills in physics and mathematics may not even be demanded as an entry requirement to clinical professions) and there are very few options for being taught these in-depth later. The resulting lack of expertise has generally been filled by recruiting additional staff who do have these skills but generally have poor understanding of the clinical issues or the skills to manage a patient or conduct a clinical assessment. This results in the expense of employing two professional staff neither of whom is properly qualified to perform the required role. Standards of clinical gait analysis would almost certainly rise if a new profession of clinical gait analyst was developed with the appropriate education and training to be competent in all aspects of the clinical gait analysis process.

The level of detail of this book is intended to be sufficient to summarise all of the key areas with which the clinical gait analyst should be familiar. In places this summary may be difficult to follow unless the analyst has some existing understanding of the underlying concepts which draw from a large number of disciplines including (but not limited to) anatomy, physiology, biomechanics and measurement theory. In that case they may need to refer to other more basic text books from the individual disciplines. In other places the summary may not appear specific enough and they will have to think quite carefully about how general principles can be applied in specific situations. Both of these limitations reinforce how difficult it is to perform high-quality clinical gait analysis and what demands it makes of the clinical gait analyst. Whilst challenging this should be welcomed as it is this that guarantees continued employment for those highly educated and experienced professionals who constitute the gait analysis workforce!

There has always been a symbiotic relationship between clinical service delivery and clinical research in gait analysis. In an emerging field this was essential to develop new techniques for data capture and analysis. As the field matures and we begin to understand more and more how clinical gait analysis should be performed, however, it is necessary to start to differentiate these activities. This is important because high-quality service delivery and research activity require quite different attitudes. Modern clinical services operate within a framework of clinical governance. This requires staff with clinical training and experience to deliver practice in line with well-defined protocols based on the established evidence base. Research, on the other hand, flourishes in an environment of experimentation that pushes practice beyond that evidence base. The first responsibility of any modern clinical gait analysis service is to ensure the delivery of standardised evidence-based measurement services to patients. The aim of this book is to describe how to do this. Much of the detail, however, will also be of use to those interested in clinical research, particularly those who want to use established technologies in different research applications.

**Gait analysis and cerebral palsy**
The pioneering clinical gait analysis services that first made use of kinematic and kinetic measurements all worked with children with cerebral palsy. The early focus was
on assessing children for complex orthopaedic surgery and this has been extended to include other interventions such as selective dorsal rhizotomy, injections of botulinum toxin and prescription of orthoses. There has been a strong historical relationship between developments in clinical gait analysis and the care of the ambulant child with cerebral palsy.

Although patients with cerebral palsy are probably still the only group where there is reasonably widespread agreement in how and why clinical gait analysis should be conducted, a growing number of centres are starting to apply the techniques more widely. In a recent informal survey of European gait analysis services less than 50% of appointments were for children with cerebral palsy or similar conditions. Gait analysis for other conditions is a rapidly growing field, and there is no doubt that over coming years clinical gait analysis will come to be less automatically identified with cerebral palsy than it is at present.

The conventional approach to clinical gait analysis that this book aims to describe emerged within the pioneering centres that were focusing on children with cerebral palsy. Most of the key chapters are simply about good measurement practice and although methods were originally developed for use in one patient group they are generally applicable across all patient groups. The major exception to this is the chapter on physical examination which is focused on a paediatric neuromusculoskeletal assessment. Those working in different fields will need to modify this to reflect their own requirements. They should remain alert for other areas in which the requirements of their own particular practice might differ from the methods outlined within this book.

**Different aspects of clinical gait analysis**

Defining gait analysis as the process of determining what is wrong with a patient is rather too vague for practical purposes. In this book it will be assumed that the more specific aim of gait analysis is to define what impairments are most likely to be affecting the patients’ walking pattern. This will be referred to as *impairment-focused gait analysis*. Following World Health Organization’s recommendations impairments are defined as *a problem in body structures or functions such as significant deviation or loss* (WHO 2001). Hip flexor contracture, persistent femoral anteversion, gastrocnemius spasticity and gluteus medius weakness are all impairments. Defining gait analysis in this way distinguishes it clearly from clinical decision-making. While there appears to be a small step between suggesting that a child’s walking is affected by a hip flexion contracture and recommending that they should have a hip flexor release there is a considerable gulf conceptually (and medico-legally). This book assumes that the outcome of a clinical gait analysis is a description of the impairments most likely to affect walking ability.

As we have seen this maps onto the surgical decision-making processes and is particularly suited to orthopaedic management with children with cerebral palsy. Neither the orthopaedic surgeon nor anyone else (at present) can do anything to
repair the brain damage that is the fundamental cause of cerebral palsy, but they are able to operate on secondary impairments that have developed as a consequence of the underlying condition. Orthopaedic surgery is limited to rectifying these impairments and being given a list of what these are likely to be by a gait analyst is extremely useful.

This information may be less useful in different contexts, particularly perhaps in areas where gait analysis has considerable potential but is not yet routinely used. In gait rehabilitation, for example, where simply removing the impairments is not possible, it might be far more useful to understand how patients are achieving function despite the impairments that are affecting them. Rehabilitation can then focus on augmenting existing compensatory strategies (or even suggesting new ones). This approach could then be referred to as function-focused gait analysis.

At present function-focused gait analysis is much less well developed than impairment-focused gait analysis. The impairment-focused approach is based primarily on the recognition of patterns in the data. Function-focused gait analysis is much more challenging in that it generally requires a much deeper knowledge of the underlying biomechanics and an ability to relate these to the functional requirements of walking. There are few contemporary gait analysts capable of delivering such analyses. The basic techniques for making measurements are the same regardless of which of these two approaches are adopted but in considering how data are interpreted this book will focus on the impairments-focused approach.

A little separate from either impairment- or function-focused gait analysis is the role of gait analysis in monitoring progress and documenting outcomes. Whilst documentation of outcomes within formal clinical trials is clearly the remit of clinical research, a very important role of routine clinical gait analysis services has always been to provide data to allow clinicians to reflect on how individual patients are progressing and particularly how they have responded to earlier interventions. This is important in the ongoing management of the individual patient but may be even more important in developing further the clinician’s appreciation of how to manage other patients in the future. Clearly the fundamental requirement of using any measurement technique for this purpose is confidence that differences between measurements made on different occasions are a consequence of real changes in the patient and not simply of inconsistencies in how the measurements are made.

Whatever the application, the fundamental requirement of clinical gait analysis is for high-quality data that accurately and precisely record how the patient is walking. The fundamental purpose of this book is to describe how to provide such data. Even in a book of this length on what appears to be an extremely specific topic, however, it is only possible to do this at a rather general level. Individual analysts in individual clinical services will still need to adapt the general principles outlined to the specific requirements of their own professional practice.
Chapter 1 Introduction

References