1

Introduction

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> *In solving a problem of this sort, the grand thing is to be able to reason backward. That is a very useful accomplishment, and a very easy one, but people do not practise it much.*
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> Sir Arthur Conan Doyle: *A Study in Scarlet* (2010, p. 83)

> *Biomechanics has its own terminology that is based upon that of mechanical engineering. The translators of the code of biomechanics are the engineers who have developed their own jargon. It is our intent to reveal some of the fundamentals of biomechanical testing and many specific testing techniques. In so doing, we hope to disperse the mystique shrouding biomechanics.*
>
> Turner and Burr (1993, p. 595)

Biomechanics is a new, exciting and powerful discipline that is shaping a broad range of subjects such as medicine, sports science, botany, zoology, ergonomics, accident reconstruction, occupational health, palaeobiology, dentistry and, most recently, forensics. Many of these areas have developed sophisticated biomechanical techniques with their own algorithms, notation and specialised methods. This combination of breadth and depth makes it impossible for any one individual to master all of the biomechanical approaches that have been developed. The aim of this book is thus twofold; it introduces general concepts that apply to the field as a whole, and it applies these to the broad discipline of forensic biology.

Whereas it is difficult to identify a father of biomechanics, one could argue that biomechanics is as old as mechanics itself. The Italian renaissance scientist, Leonardo da Vinci (1452–1519) studied the biomechanics of the flight of birds and, by extension, hypothesised how humans could fly. Galileo Galilei (1564–1642) investigated the strength of bones and suggested that they were hollow, because this gave them a maximum strength for minimum weight. Rene Descartes (1596–1650) proposed a philosophical view that saw all material systems, including the human body, as machines ruled by simple mechanical laws; an idea that did much to promote and sustain the biomechanical studies of Giovani Borelli (1608–1679) and others (for review, see Humphrey, 2003).

The term *Biomechanics* itself has only recently been defined by the South African scientist Herbert Hatze (1937–2002) as ‘the study of the structure and function of biological systems by means of the methods of mechanics’ (Hatze, 1974, p. 189). He

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was at pains to stress that, because biological systems cannot have mechanical aspects, one cannot apply pure mechanics to such systems. By way of example, consider the trajectory, velocity, spin, angle of impact etc. of a bullet striking a living target. Before impact, the simple laws of mechanics govern all aspects of the projectile's travel. The situation changes immediately upon impact: we now have to draw on vastly more complex biomechanical aspects of the tissues involved to interpret the resultant pattern of wounding, path of travel, bloodspatter and so on. In this book, we accept *forensic biomechanics as the study of forensic biological phenomena by means of the methods of mechanics, in terms of the structure and function of relevant biological systems.*

Modern biomechanics had its roots in the 1970s, when digital computers became more generally available and when the *International Society of Biomechanics* was founded. A key pioneering publication was that of *Biomechanics: Mechanical Properties of Living Tissues* by Y. C. Fung (1993), who characterised the field as mechanics applied to biology. With the application of rigorous engineering analyses to the study of biological tissues in the seventies and eighties came the realisation that conventional mechanical methods were generally inadequate to model biological tissues. Bone, for instance, behaved in a linearly elastic fashion, and yet it was anisotropic, with mechanical properties dictated by its micro- and macroarchitecture. Skin and other soft tissues exhibited anisotropic viscoelasticity, and blood was found to behave in a non-Newtonian fashion. These behaviour patterns required a new set of theoretical frameworks, motivated by observations in living tissues, which in turn were subjected to more observation, using increasingly sophisticated methods such as scanning electron microscopy, nano-indentation and micro-CT (micro-computed tomography) scanning (Athesian and Friedman, 2009). Additionally, biomechanics was being applied to multiscale systems consisting of bodies, organs, cells and subcellular structures. To facilitate this, a multidisciplinary integrative approach, ranging from biophysics of molecules to bulk constitutive modelling, had to be developed. While forensic biology research is clearly evident at the tissue and organ level, it can and does involve several levels of hierarchy and, hence, forensic biomechanics is application focused and relies on basic biomechanical knowledge at all levels from nano- to whole body structures. Improved understanding of the role of biomechanics in the broad field of forensics will lead to new investigative approaches that will strengthen the evidentiary usefulness of forensic science in general.

We offer no apology for adding another text to the forensic science library. Our intention is simply to make the biomechanical principles of forensic biology more relevant and understandable. While making a humble contribution to the subject, this book is designed to meet the pressing need for an overall description of biomechanical principles that does not require background knowledge of mathematics. Many of us find formulae, particularly the longer ones that employ Greek symbols, daunting and incomprehensible. Most people understand basic laws of motion and relationships between factors such as stress and strain, but when faced with their shorthand mathematical expressions we experience an attention deficit problem. Unfamiliarity with algebra and calculus lie at the root of this. Here, we overcome this issue by using clarity of writing and simple examples. In doing so, we obviously risk irritating those more familiar with higher mathematical skills such as linear algebra, calculus and Fourier transforms, and we apologetically refer them to those more involved texts that might suit their needs better. Hence, the basic premise of this book is that most forensic biological principles can be understood and used without the traditional barriers of higher mathematics and theory. We wish to emphasise that this book is intended to serve a distinctly humble purpose; it introduces biomechanical principles that are useful in understanding or interpreting some forensic evidence such as trauma, bloodstain patterns and damage to natural fibres and fabrics.

The structure of the book as a whole will be evident from a glance at the table of contents. Chapter 1 introduces the subject of biomechanics and places it in the context of forensic biology. The fundamental guiding principles that are key to understanding forensic biomechanics are presented in a clear, step-by-step fashion in Chapter 2. Whether you have a mathematical background or not, this will provide you with a new and interesting perspective on forensic investigation. While the biomechanics of bone and bony trauma is the subject of Chapter 3, skin and soft tissue trauma are covered in Chapter 4. The intention of both these chapters is to provide a basic overview of the structures and processes involved, not to spend an inordinate amount of time on mathematical details. Chapter 5 describes the biomechanics of bloodspatter from the viewpoint of the forensic investigator, showing the physical principles underlying bloodstain pattern formation. Chapter 6 describes the architecture of natural fibres, yarns and fabrics and discusses how these are affected by blunt, sharp and ballistic impacts.

A modest mathematical/physics background is required to understand the material presented here. The reader is expected to have a basic understanding of physics and to be familiar with biological structures such as cells and tissues. Readers do not need sophisticated mathematics, nor do they need to know the details of kinetics, ballistics or viscoelastic, or non-Newtonian behaviour.

The book is now in the hands of its most important critic: you. Your criticisms, comments and suggestions are very important to the continued evolution of this work. All it takes is a three-minute email to jules.kieser@otago.ac.nz. Thank you so much, we hope you enjoy this book.

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