LIGAMENT INJURIES
and their Treatment

Edited by

D. H. R. Jenkins MB, ChB, ChM, FRCS

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Consultant Orthopaedic Surgeon
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Preface

The continued popularity of sporting activities and the concomitant intensity of training and participation has resulted in higher incidences of ligament injuries. This book, written by an international team of specialists, brings together recent advances in treatment. It deals mainly with injuries of the knee joint, but the ankle and elbow are also covered.

The book is divided into three parts. Part One on structure and function, deals with the biomechanical aspects of ligaments. The structure of ligaments and anchorages, together with comments on the mechanical properties and actions of ligaments and joints, are also discussed. These topics are followed by a chapter on collagen metabolism and healing.

Part Two forms the main part of the book and is concerned with treatment. It is well recognized that in 1985 the major interest in the ligament field concerns the knee. It is, however, relevant to have comments on other joints, and for these reasons the elbow and ankle are also included.

Part Three is on the use of graft materials and deals primarily with carbon fibre, although there is one chapter on the use of bovine xenografts.

Collectively, this book presents a view of ligament problems from both sides of the Atlantic. It is aimed at the surgeon who is interested in ligamentous instability, and sets out to present the current view of those who are active in this field.

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Contents

Contents

PART TWO: Treatment

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PART ONE
Structure and Function

1 *Biomechanics of ligaments*

ANDREW A. AMIS

1.1 Introduction

The purpose of this chapter is to examine the behaviour of ligaments in a wide-ranging and fundamental manner, which should help to explain many of the clinical details in subsequent chapters. This applies particularly to aspects such as the function of ligaments, their failure or disruption, and attempts to repair them or simulate their structures by artificial replacements. The basis of a sound understanding of all these aspects lies in an appreciation of their mechanical characteristics. A surgeon reading this might be tempted to think that mechanics is not really important when faced by clinical reality. However, patients with a ligament problem are in that position primarily because they have contrived to overload their complex musculoskeletal mechanisms, and an understanding of the mechanism of injury will often provide the guidelines for a surgical reversal of the disruption.

Subsequent discussion will deal with ligaments on two levels: a review of the properties of isolated specimens of ligamentous tissue, then a review of how bundles of this tissue act to control the motion or stability of joints.

1.2 The structure of ligaments

The structure of any ligament is basically that of a bundle of fibres which link two bones. This structure normally functions to control the relative motions of the two bones, the most common mode of action being that the ligament inhibits the separation of two points on the bones by providing a tensile restraint to that motion. Any further excursion may be accomplished only by exerting sufficient force to extend the ligamentous structure. The ligaments function in a passive manner – if the bones approach each other, then the ligaments slacken and have no influence on the relative movements of the bones. This mechanism is demonstrated by rheumatoid disease, for example, which shortens the bone ends spanned by ligaments by a process of erosion, so that the ligaments are then powerless to prevent the occurrence of subluxation or other deformity – an abnormal relative motion of the bone ends. Conversely, if the bones try to move apart, the restraining forces exerted by the ligaments are determined solely by the tensile (extension versus force) characteristics of their structures.

For this biomechanical review, the functional characteristics described above should be borne in mind as a means of elucidating the significance of the detailed features of the structure of ligaments.

Atomic and microscopic details of the structure of ligamentous tissue have been published by various authors (Viidik, 1966; Tkaczuk, 1968), whose descriptions may be summarized as follows: the basic structural material is collagen. This is a high molecular weight protein, whose long chain molecules arrange themselves along protofibrils. The protofibrils group together to form fibrils, which themselves group together into the bundles which make up the ligament. The essential structural feature of this hierarchy is that the smaller elements always arrange themselves parallel to the major axis of the larger structure in which they are incorporated. This means that the structural protein molecules are arranged along the length of the ligament, adapting it perfectly to resist tension. Trapped within the fibrillar collagen structure are small volumes of other materials: fibroblasts, or fibrocytes, which provide the cellular origin of collagen protein; some elastic fibres (principally in postural ligaments); and an intercellular ground substance. The latter is a viscous hydrophilic material, containing mucopolysaccharides, which can trap or contain water. This viscous medium is believed to control the ease with which collagen fibrils may rearrange themselves. Thus, although it is not itself structural, the ground substance does affect the response of the structure to loads, as will be discussed later.

Although collagen structural fibres surrounded by a ground substance are common both to ligaments and bones, the ground substance of bone contains inorganic material – hydroxyapatite crystals. These crystals give bone its rigidity, and may well have a bearing on the tendency of bones to fail in tension. The structural problem for ligaments is that an anchorage to bone involves bridging a transition from the soft ligament material to the relatively rigid bone. Fortunately, histological examination shows that there is a gradual transition of material types at the interface, thus avoiding stress concentrations which would weaken the structure.

The insertions of ligaments into bones may be classified roughly into two types, depending on whether the ligament approaches the bone surface at a large angle (for example, the cruciate ligaments of the knee), or tangentially (for example, the tibial insertion of the medial collateral knee ligament). If the ligament approaches at a large angle, its collagen fibres continue on into the bone structure, as Sharpey's fibres (Viidik, 1966). The cellular material between the fibres transforms from fibrocytes to a 'chondrocyte' appearance, and then to osteocytes (Ham, 1953). These cellular changes reflect the material types, which have been classified as four layers: ligament, fibrocartilage, mineralized fibrocartilage, then bone, which has a hard cortical shell overlaying a trabecular structure (Noyes, DeLucas and Torvik, 1974). The fibrocartilagenous layers provide a zone of mechanical property transition, thereby avoiding stress concentrations at the interface.

When a ligament meets the bone surface tangentially, however, most of its fibres do not penetrate deeply into the bone, but dissipate themselves into the fibrous periosteal layers, normally over a large area (Laros, Tipton and Cooper, 1971; Noyes *et al.*, 1974). Although the cellular material goes through a chondrocyte transition at the interface, there is no fibrocartilage zone, so that fibrous tissue lays directly on the bone cortex. This difference in anchorage morphology causes a differing response to exercise or immobilization – the relatively vascular fibrous tissue anchorages being more susceptible to deterious changes.

Although it is generally accepted that ligaments have a very low rate of metabolism, their tissues do contain an adequate vascular supply to enable slow healing to occur, and nerve fibres are associated with the blood vessels. This is so even within the mid-substance of the cruciate ligaments, which is probably the site most remote from well-vascularized surroundings (Kennedy, Weinberg and Wilson, 1974). The paravascular nerve fibres probably provide a sensory feedback to warn when joints are reaching their limits of motion – a function which an artificial ligament could not duplicate.

1.3 The mechanical properties of ligament tissue and isolated ligament specimens

Many people have published the results of studies of the strength of ligaments, yet, as will be shown later, very little of the material is of use for providing surgeons with data which may be used as guidelines for reconstructive procedures. A major barrier between laboratory work and realism is the complex nature of real injury mechanisms, few of which have been recorded (for example, when a football player's injury has been televised). Analysis of falling and twisting movements requires films shot simultaneously from two directions, so perhaps it is not surprising that such data is not available. Studies of ligament strength have therefore confined themselves to relatively simple tests, in which bones are clamped into machines and pulled apart in a particular direction. Even on this simpler level, however, there is great scope for error, so results must be viewed critically.

1.3.1 TYPICAL TENSILE BEHAVIOUR

Typical tensile behaviour of ligament material is shown in Fig. 1.1. The initial extension, into region 1 on the graph, from the origin, occurs for a very small load. The upward curve of the graph indicates that the ligament becomes progressively stiffer as it is stretched through region 1, until the slope of the graph reaches a maximum gradient, which is maintained through region 2, indicating a constant stiffness (amount of force per extension).

Constant stiffness is a feature of normal Hookean elastic behaviour, but the elastic line should pass through the origin, as shown. There are two main reasons why this does not happen for ligaments. Firstly, the fibrous structure of a relaxed ligament does not have all the collagen fibres pulled straight and parallel – they buckle into a wavy configuration – so the initial extension, for a low load, is pulling the fibres straight rather than stretching them. Once straight, their elongation is of an elastic nature (region 2). This mechanism was shown by Rigby *et al.* (1959), using a polarizing microscope. The second reason is that ligaments originate or insert over areas of bone, rather than at points, so there will be a range of fibre lengths within each ligament. Since, also, ligament fibres are not arranged as regularly as in a tendon, for example (Viikik, 1966), it seems

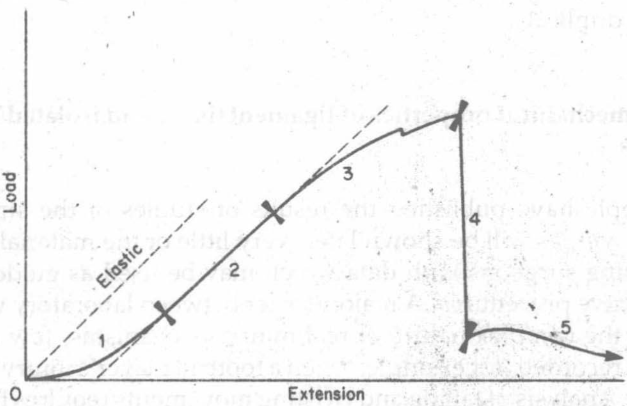

Fig. 1.1 Typical tensile load versus extension behaviour of a ligament; regions 1–5 are explained in text.

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