Abstract. Scanning probe methods have been utilized to reveal useful information regarding the tribological phenomena of total joint replacement materials. In particular, studies on the effect of synovial fluid constituents on the tribological response of polymeric materials and the effect of residual stresses on the fretting response of metallic materials are described. The studies show that an adsorbed layer of proteins causes an increase in friction behavior of hydrophobic ultrahigh molecular weight polyethylene (UHMWPE) owing to denaturation upon adsorption. Changing the crystallinity of UHMWPE can affect the friction behavior and have ramifications for mechanisms of protein adsorption. Studies on fretting behavior of metallic (CoCrMo) implant materials showed that significant plastic deformation of the metal may not be a prerequisite for oxide fracture. In addition, results suggest that nearly neutral boundary lubricants may provide significant protection against the onset of fretting. Finally, the chapter concludes with an outlook on how scanning probe methods can be used to provide greater insight into the design of biomaterials.

Key words: Total joint replacements, Ultrahigh molecular weight polyethylene, Polyethylene, Atomic force microscopy, Friction, Wear, Proteins

25.1 Introduction

This chapter describes examples of scanning probe applications in the field of bioengineering and biomaterials, specifically the area of understanding and improving the tribological behavior and durability of joint replacement materials. The chapter begins with an introduction to total joint replacements (TJR), including the problems being studied and the far-reaching impact of finding potential solutions. Examples of scanning probe methods used and the results obtained are then described. The chapter concludes with a summary and future outlook.

25.1.1 Total Joint Replacements

TJR is a procedure in which damaged joints are removed and replaced with an artificial device (prosthesis). Each year, more than a million total replacement surgeries are performed worldwide, with a predominant number being hip and knee replacements. A natural hip joint, shown in Fig. 25.1, is a ball-and-socket joint that
Fig. 25.1. A natural hip joint and related components

allows movement in three planes. The head of the femur mates with the socket of the pelvic bone to form the articulating joint. These bearing surfaces are lined with a 1–3-mm-thick layer of human cartilage and operate in the presence of a natural joint fluid known as the synovial fluid. A typical total replacement hip joint is shown in Fig. 25.2a, in which the bearing surfaces are formed by the acetabular liner (usually a polymer) and the femoral head (usually a ceramic or metallic alloy). Most replacement joints are modular in nature as shown in Fig. 25.2a. The acetabular shell and the hip implant are embedded into the bone using cement or using a press-fit.

25.1.2
Social and Economic Significance

Researchers have estimated that the demand for TJRs is expected to increase dramatically in the next 25 years [1–3]. A study conducted by the American Academy of Orthopedic Surgeons [2] projects the number of yearly procedures for primary (first-time) total knee replacement to jump by 673% to 3.48 million in 2030. The number of primary total hip replacements performed yearly will increase by 174% to 572,000. The research team based its projections on historical procedure rates from 1990 to 2003, combined with population projections from the US Census Bureau. Reasons for the expected increase include an aging population with arthritis requiring joint replacement; the increasing prevalence of obesity, which puts undue stress on the knee and hip joints; and the trend toward baby boomers remaining physically active later in life, which also places demands on the joints.

25.2
Problems Associated with Total Joint Replacements

Though joint replacement procedures are mostly successful, the artificial joints can become loose and unstable during use, which is commonly referred to as aseptic loosening (Fig. 25.2b). The TJRs thus often require revision surgeries to repair or replace the joint. Herbert et al. [4] have reported that a revision surgery costs three to four times more hospital resources than a primary implant. The number of revision surgeries likely will double by 2015 for total knee replacement and by 2026 for total