Summary

Constraint is limitation of motion in a joint, e.g., due to an axis mechanism or to conformity between two articular surfaces. In addition to flexion and extension, the normal knee has some anterior-posterior translation and rotates around a vertical axis. If these motions are impeded by excessive constraint in a prosthetic design, no physiological motion will be possible. Unfavorable long-term results and complications have been reported in this setting. Possible sequels of excessive constraint are fatigue of the bone-prosthesis interface, limitation of motion, patellar displacement, or periprosthetic fracture.

Constraint

Constraint is limitation of motion between two bodies linked by a joint. In human joints, constraint may be normal, i.e., by ligaments, capsules, or articular surface geometry; it may be pathological, i.e., by contractures or arthrosis; and it may be artificial, i.e., by implants.

Unlimited motion has 6° of freedom: three rotations and three translations (Fig. 11-1). In constrained motion, one or more degrees of freedom are diminished or abolished. The ultimately constrained joint is a hinge joint, which has only one rotation and no translation.

In a normal knee joint, rotation around a horizontal axis, i.e., flexion and extension, is by far the most important motion. The usual flexion-to-extension range is approximately 150°-0°. In addition, external tibial rotation during extension, i.e., rotation around a vertical, also occurs and amounts to approximately 15° through the full flexion-to-extension range. This has been referred to as the screw-home mechanism. Translation is mostly along an anterior to posterior axis and may amount to 10-15 mm through the full flexion-to-extension range [15, 18]. This is commonly referred to as the roll-back mechanism. It shifts the tibia away from the femoral condyles in maximum flexion, providing additional flexion range. Thus, physiological knee motion has more than one degree of freedom range. Motions in addition to flexion and extension have to be taken into account in knee joint replacement.

Constrained Knee Designs

In knee joint replacements, motion may be constrained with one or more axes built into the implant. Hinged motion around a horizontal axis, i.e., with one degree of motion freedom, was implemented in the first knee replacement designs. They are referred to as first-generation hinge implants.

The Walldius hinge prosthesis was introduced in the 1950s [25] and was originally made of acrylate; this was later changed to cobalt-chromium. Shiers published a preliminary report of his metal hinge prosthesis for use with bone cement in 1954 [21]. In the 1970s, a hinged design with a patellar flange was described by the French Guépar group (Groupe pour l’utilisation et l’étude des prothèses articulaire).

Hinged implants were relatively easy to use because all the ligaments could be resected at the time of the arthroplasty and alignment was determined by the stems. However, some authors reported unfavorable long-term...
results with these prostheses: e.g., a complication rate of 23% for hinged implants [10], 29% poor results [12], and a 70% complication rate [9] for the Guépar prosthesis, and unfavorable results for the Walldius implant [11]. The probability of the prosthesis remaining in situ after 6 years in osteoarthritis was calculated as 65% for hinged prostheses, compared with 90° for medial unicompartmental prostheses. Also, severe bone loss made salvage by arthrodesis difficult [14]. Better results were reported for Implants that combined hinged motion with a metal-to-polyethylene articulation (slide and hinge principle), such as the St. Georg hinge [7] and the Blauth prosthesis [2], introduced in the 1970s.

In subsequent prostheses, such as the St. Georg rotation knee, introduced in 1979, rotation around a vertical axis was added, giving the joint two degrees of freedom. These joints are generally referred to as second-generation rotating hinge joints and are in common use today.

Other models added some anterior-posterior translation as a second degree of freedom by linking the femoral and the tibial component with a tibial metal post running in a femoral cam, such as the GSB implant [6]. However, this prosthesis yielded unfavorable results after 7.8 years [22].

Another way to constrain knee motion is to vary the contact design between the femoral component and the upper surface of the polyethylene insert. These prostheses are generally referred to as semi-constrained implants. Generally, constraint is proportional to the conformity between the two surfaces: If both surfaces are in total contact, i.e., if the radii of curvature are equal, motion will be pure rotation and no translation will be possible. This is implemented in so-called constrained condylar, total condylar, or deep-dished designs. If the insert is flat, i.e., if the radius of curvature is greater than in the femoral component, some translation will be possible in addition to rotation. Also, polyethylene posts or spines at the upper surface of the insert that engage into a femoral cam can prevent certain motions. The cam-spine mechanism is most commonly used to prevent posterior translation of the tibial component in posterior-stabilized total knee designs. Some knees also use the cam-spine mechanism to prevent rotation around a sagittal axis, i.e., medial and lateral instability.

The classic semi-constrained knee is the total condylar constrained knee prosthesis (TCP III), which was introduced in 1977 to provide greater stability and constraint with a non-linked implant. In 1988, the TCP III eventually became the Insall-Burstein II constrained condylar knee prosthesis (CCK), which was modular.

### Indications for Constrained Designs

A knee with functional ligaments and with limited axial deviation is now generally considered an indication for an unconstrained condylar prosthesis. The use of constrained designs in this setting has generally been abandoned.

Unstable knees usually necessitate some degree of constraint. The notable exception is the anterior cruciate ligament; it is resected in most bicondylar knee replacements. Therefore, almost all prostheses have sufficient articular surface congruity to compensate for lost anterior ligamentous stability. The posterior cruciate ligament, which may be primarily insufficient or lost due to resection of its tibial insertion, has to be replaced with a posterior constraint, which is usually provided by a polyethylene spine of the insert reaching into a femoral component cam. Medial or lateral collateral ligament insufficiency, if significant, requires a design which eliminates rotation around a sagittal axis. This will most commonly be a rotation hinged knee, which rotates only around a vertical and frontal axis.

Another indication for a constrained knee is significant axis deviation. The maximum accepted deformation for a surface replacement prosthesis is somewhat variable. However, varus or valgus angulation beyond 20° as a rule requires a medial or lateral release and increased height of the polyethylene insert. In axis deviation of more than 20°, this height may exceed 20 mm, which makes it prone to raising the joint line and technical failure. Therefore, a constrained rotation knee design is preferable in this situation. This setting is quite common in patients with rheumatoid arthritis. Bone defects in tumor reconstructions may also require a hinged implant [16].

### Constraint Sequels

The ligaments and capsule of a normal knee and of a knee following surface replacement are able to absorb a substantial amount of energy. During normal gait, this energy peaks during push-off at late stance phase and during touchdown of the foot at the beginning of stance. However, forces at the knee joint are created by body weight, by muscle power, and by acceleration and deceleration. Therefore, significant forces occur throughout the entire gait cycle and not just during the stance phase. The soft tissues of the knee joint, in particular the cruciate ligaments, the collateral ligaments, and the joint capsule, serve as shock absorbers, i.e., they absorb energy. If a knee is deprived of this mechanism, stress is transmitted directly from the prosthesis onto the implant-fixation boundary, which may result in fatigue at the prosthesis-bone interface in uncemented implants and at the cement-bone interface or at the cement-prosthesis interface in cemented implants. In addition, significant forces will be present at the hinge or other constraint mechanism of the knee, e.g., a tibial insert polyethylene spine, which may be damaged or may fail [17].