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Fixation and loosening of hip prostheses

A review

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Studies using roentgen stereophotogrammetry and bone scintigraphy support a narrow definition of prosthetic fixation (viz., nonmigration), and consequently a broad definition of loosening. Roentgen stereophotogrammetric research indicates that if loosening occurs, it is initiated at an early stage; insufficient initial fixation or loss of fixation by resorption of a layer of heat-injured bone may cause prosthetic instability and progressive bone resorption. Migration of one or both prosthetic components can be revealed by roentgen stereophotogrammetry in many asymptomatic hips during the first postoperative year—some of these components will probably fail in the future. The femoral component is exposed to greater shear stresses than the acetabular component, and it is uncertain whether fixation of the femoral component can be achieved more than occasionally without the use of bone cement.

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The cemented hip arthroplasty is one of the most successful of all orthopedic operations. However, the results do deteriorate with time because of mechanical loosening, and uncertainty has prevailed when loosening occurs, and thus on the basic cause. Radiographic identification of prosthetic loosening is often difficult (1), and bone ingrowth and osseointegration cannot be demonstrated by conventional radiography (2, 3). Consequently, because radiographic changes may occur late in the course of loosening, many authors have suggested or implicated late prosthetic loosening, and thus have restricted the use of the term "loosening" to clinical or radiographic failure. Confusion has also arisen because some hips with obviously loose prosthetic components are not painful (4–6).

Definition of fixation and loosening

By comparing the results of contrast (7, 8) and radionuclide (9, 10) arthrography, bone scintigraphy (11–13), and roentgen stereophotogrammetric analysis (14–16) (comprising both instability upon provocation, and migration over a period of time) in a series of hip prostheses a broad definition of prosthetic loosening can be proposed: viz., migration according to roentgen stereophotogrammetric analysis (17). Regardless of diagnostic criterion on loosening, all loose prosthetic components were migrating, but no nonmigrating component was loose (Figure 1). Some readers may argue against that a slightly migrating prosthetic component is to be regarded as loose (18), as such a component usually remains asymptomatic for many

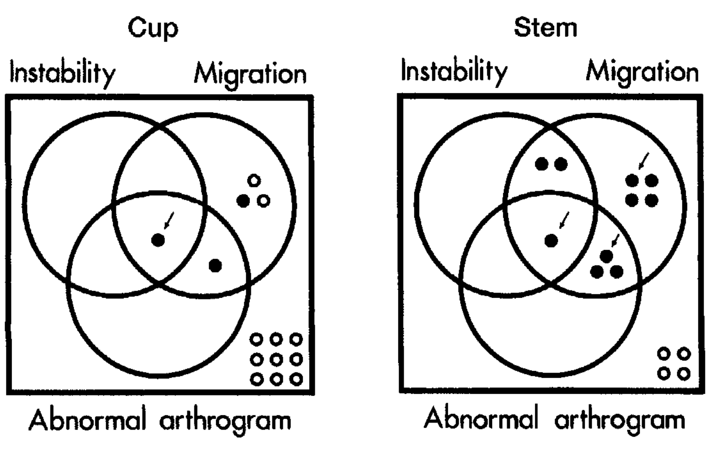

Figure 1. Relation between instability and migration revealed by roentgen stereophotogrammetry, contrast and radionuclide arthrography, and bone scintigraphy of the acetabular component (left) and of the femoral component (right) in 14 prosthetic hips. ● increase in scintigraphic activity. ○ no increase in scintigraphic activity. Arrows indicate revised components because of clinical loosening. Note the high correlation between migration and increased scintigraphic activity for the femoral component. The increased activity around the acetabular component was, however, more difficult to evaluate because of the deep position of the component and activity caused by the bladder. (Reproduced with permission of *Acta Orthop Scand.*)

years (6). However, if the definition of loosening is made broader, the definition of nonloosening becomes correspondingly narrower. The advantage of having a narrow definition of prosthetic fixation (rather than of prosthetic loosening) is that components that fulfill this criterion will probably not fail (6, 17, 19). Roentgen stereophotogrammetry (17, 19) and bone scintigraphy (11–13, 17) have demonstrated the possibility of stable and nonmigrating prosthetic components (Figures 2 and 3). Further, histologic (20–23), and ultrastructural (24) investigations have shown that close contact between viable bone and the cement or an implant may occur in the prosthetic hip. A consequence of this narrow definition is that prosthetic fixation cannot be demonstrated by arthrography, by provocational investigations using roentgen stereophotogrammetry (Figure 1), or by apparent stability at revision (25–27). Accordingly, the osteolysis and pain reported in some apparently stable prosthetic components (25–30) may be due to prosthetic instability.

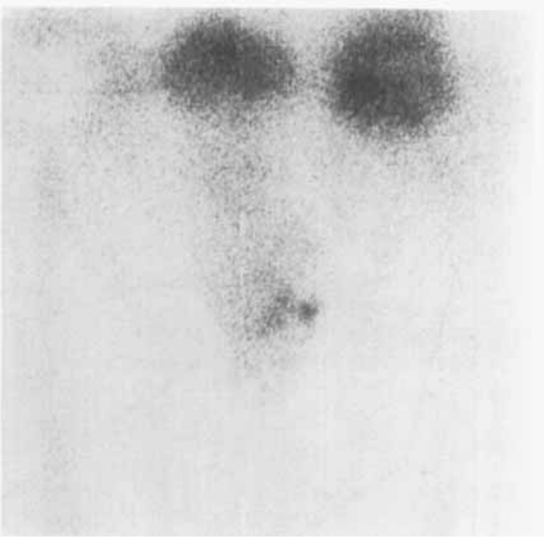

Figure 2. Bone scintigraphy of a nonmigrating cemented femoral component 2 years after arthroplasty of the right hip. (The increased activity of the left hip is due to arthrosis.)

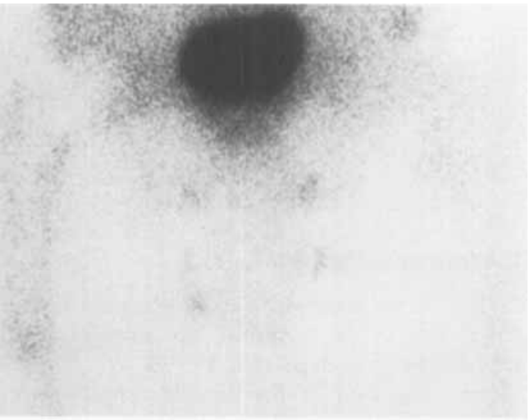

Figure 3. Bone scintigraphy of a migrating cemented femoral component 2 years after arthroplasty of the right hip. Note the focally increased activity at the tip of the migrating femoral component.

The cemented hip arthroplasty

The acetabular component

Migration of the acetabular component is more common than of the femoral component in the cemented hip arthroplasty for arthrosis (17, 19). This can partly be explained as a consequence of heat injury to the acetabular bone during the polymerization of the cement: The threshold temperature for heat injury of bone is about 47 °C for 1-minute exposure (31, 32), but this threshold temperature might be even lower when the bone is exposed to monomer that has leaked out from the cement dough. Labitzke and Paulus (33) recorded, by measuring the temperature at the bone-cement interface, the average peak temperature as being 50.4 (± 7) °C in the acetabulum and 45.2 (± 4) °C in the femoral canal—in both the cases arrived at from an initial bone temperature of 37 °C. These findings accord with the theoretical analysis of heat conduction in the hip by Huiskes (34): viz., the metal of the femoral component acts as a heat sink. Apart from using metallic implants, the risk of heat injury can be reduced by other measures, e.g., by keeping the cement layer thin (17, 34, 35), by irrigating of the bone bed with cold saline prior to the cement implantation (36, 37), and by using bone cement with reduced exotherm (38). Heat injury to bone may, however, also occur if reaming is performed with a rotating power reamer at high speed under dry conditions (39). In case of heat injury, most necrotic bone will be resorbed during the first 4 months (Figure 4) and will be replaced by fibrous tissue, which contains macrophages (40, 41) that resorb bone upon stimulation by micromovements (42–48). In case of no bone resorption, mechanical experiments (49, 50) indicate that in arthroplasty for arthrosis the strength of the bone-cement interface is sufficient for fixation of the acetabular component if all the cartilage and tissue debris are removed. The increased rate of acetabular-component failure in

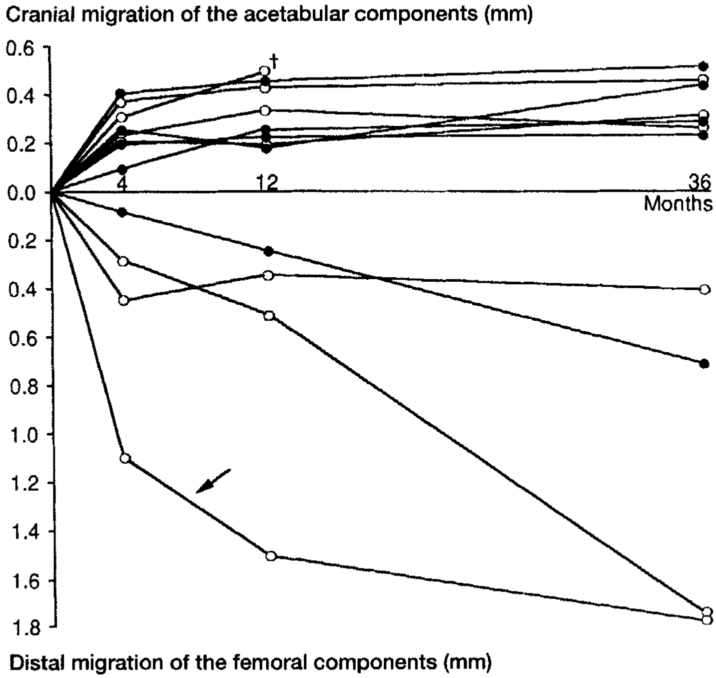

Figure 4. Migration along the longitudinal axis of the migrating 8/16 acetabular and 4/14 femoral components. ● high-viscosity cement (Palacos R cum gentamicin, Merck) and ○ low-viscosity cement (Palacos E cum gentamicin, Merck). Arrow indicates the only femoral component associated with slight pain initially at weight bearing. Note that 8/16 acetabular and 10/14 femoral components did not migrate (significance limit = 0.2 mm) during the 3-year observation period; and that in all the cases but 2 (1 acetabular and 1 femoral), the migration was seen within 4 months after surgery. (Reproduced with permission of *Acta Orthop Scand*.)

rheumatoid arthritis (51) may, however, be caused by insufficient initial prosthetic fixation in the osteoporotic bone (52).

The femoral component

Contrary to the acetabular components, most femoral components in the cemented hip arthroplasty for arthrosis are well-fixed (13, 17, 19, 20, 53); the frequent migration of the femoral components in revision arthroplasties (54) is probably due to insufficient shear strength of the bone-cement interface (55) or to the larger risk for heat injury in cases with a wide femoral canal (17). The most common cause of loosening of the cemented femoral component in primary hip arthroplasties is, however, not heat injury, but inadequate surgical technique: Residual weak cancellous bone in the femoral canal (4, 56, 57), inefficient filling of cement (4, 6, 53, 57) including cement displacement by bleeding when using low-viscosity cement (58), and tissue debris (59, 60) may give insufficient mechanical support for the cement—and unconstrained cement cannot adequately support an implant (61).

Bone cement itself, however, is not a weak link if the prosthesis is well fixed (62). If the cement is not adequately supported by cortical bone, the cement (with or without improved strength) cannot resist the local stress concentrations, resulting in a fracture of the cement and a slip of the femoral component (63, 64). Then, neither the cement nor the bone can resist the fretting effect of micromovements at the interfaces (42–48). The focal femoral osteolysis reported in some obviously unstable (25, 30, 65, 66) and some apparently stable (25, 29, 30) femoral components (often associated with midthigh pain) may be the result of joint fluid (and wear debris) being pumped with high pressure through a fracture in the cement mantle to the endosteal surface of the femur by micromovements of an unstable femoral component (67). Products of plastic and metallic wear (68–72) might possibly accelerate this bone resorption by foreign-body response—if so, then mainly when combined with major prosthetic instability.

By contrast, in cases of prosthetic integration, which may occur within 5 months after surgery (73), a biological barrier prevents the spreading of wear particles from the joint cavity (43, 74). Thus, local responses to products of wear are probably consequences rather than causes of loosening (17, 75, 76).

The bone-cement interface of the femoral component is exposed to greater torsional shear stress than that of the acetabular component in hip prosthetic patients during walking and, especially, while climbing stairs, and when rising from a chair (77–82). Thus, slightly loose femoral components can be expected to develop larger micromovements and result in earlier clinical failure than most loose acetabular components (Figure 4).

The uncemented hip arthroplasty

As loosening of the cemented hip arthroplasty may be associated with a considerable loss of bone (25, 30, 65, 83)—which has been called the cement disease (83)—there is a renewed interest in the uncemented hip arthroplasty. Numerous different prosthetic designs and materials have been introduced (84) aiming at initial stability and bone ingrowth. A minority have been investigated by sensitive clinical methods, i.e., roentgen stereophotogrammetry and bone scintigraphy, for detecting prosthetic loosening. It is unclear to what extent sufficient initial stability can be achieved in hip arthroplasty without the use of bone cement.

The acetabular component

In case of loosening of an uncemented acetabular component, the migration might be expected to be slower than for the cemented one, as there is no heat injury from the cement causing rapid initial migration, and as there is no cement wear debris accelerating bone resorption later on. On the other hand, debris from external wear of a loose polyethylene cup might possibly contribute to bone resorption (75, 85).

The migration of all the threaded cups within 1 year of surgery (86) is probably due to prosthetic instability caused by a poor contact between the screw threads and the acetabular bone (87, 88). The porous-coated cups have been found to have a better chance of sustaining bone ingrowth (89), especially when screws are used to enhance the initial stability (90, 91). However, a retrieval study of porous-coated cups has demonstrated poor bone ingrowth (90), and progressive bead loosening from the porous coating in some cups (92, 93) indicates prosthetic instability.

The femoral component

A prerequisite for bone ingrowth into an implant is initial stability, i.e. only extremely small movements are tolerated (43, 46–48). Mechanical investigations (94–97) have, however, demonstrated manifold larger micromovements in uncemented femoral components than in the cemented ones. Thus, the considerable initial migration of almost all the uncemented femoral components investigated by roentgen stereophotogrammetry (98–100) can be explained as a consequence of prosthetic instability (101). Even 2 or more years after surgery, 74–100 percent of the uncemented femoral components have an increased activity at the tip of the stem at bone scintigraphy (102–105) compared with 10–20 percent of the cemented ones (13). Further, progressive bead loosening from the porous coating (92, 106) and focal femoral osteolysis (27, 107) reported in some femoral components indicate prosthetic instability. Although close contact between the bone and the distal part of the porous coating have been demonstrated (21, 22, 90), bone resorption commonly develops proximally (22, 28, 107–110). However, because close contact distally does not exclude prosthetic wobbling around an axis near the distal part of the stem (47), the phenomenon called "proximal stress-shielding" can be explained by micromovements that causes bone resorption (47, 48). Similarly, the focal osteolysis at the tip of some uncemented femoral components (27) is probably the result of micromovements around an axis near the proximal part of the stem (111).

The prosthetic collar

The advantage of a collar for load transmission to the proximal femur is under debate; opinions differ as regards whether there is significant or insignificant load transmission (64, 112–117)—whether or not collar-calcar contact is ever achieved at surgery (114). A 2–4-mm-wide resorption of bone beneath the prosthetic collar developed mainly within 4 months after surgery (Figure 5) in all (3 migrating and 17 nonmigrating) cemented femoral components in a series of hip arthroplasties investigated with roentgen stereophotogrammetry (17). This nonprogressive resorption can be explained on the basis of thermal necrosis during cutting, as temperatures well above 100 °C have been recorded during the cutting of cortical bone (118, 119). The fact that most of these femoral components without collar-to-bone contract did not migrate indicates that the collar is not essential for initial fixation of the cemented femoral component. The collar has also been suggested to serve as a secondary support to prevent subsidence of the uncemented femoral component (95, 110, 120). However, the collar does not prevent axial rotation of the femoral component, an important mode of loosening (81, 97, 100); and once the initial prosthetic fixation is lost, fixation probably cannot be reestablished (43, 44).

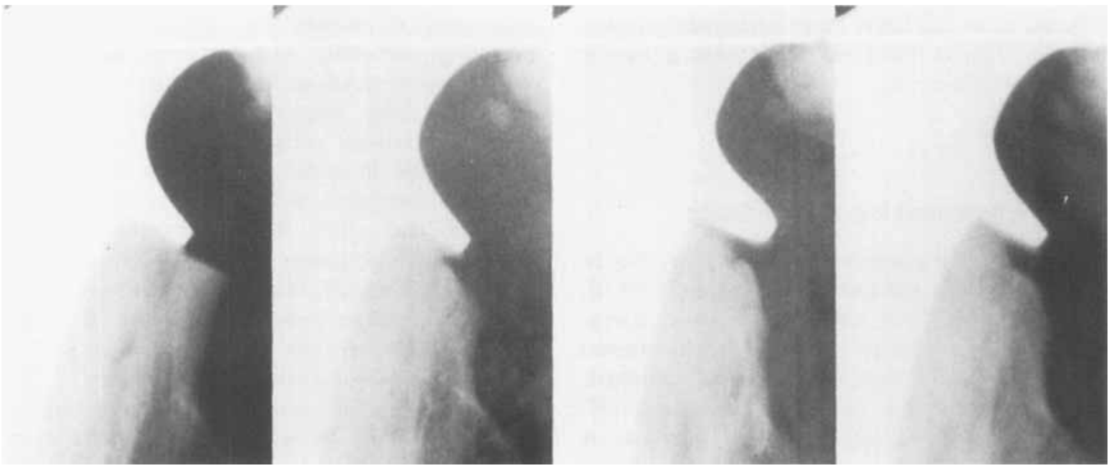

Figure 5. Resorption of bone beneath the collar of a nonmigrating femoral component 1 day, 4 months, 1 year, and 2 years after arthroplasty. (Reproduced with permission of *J Bone Joint Surg* [Br].)

Conclusions

Roentgen stereophotogrammetry indicates that loosening is a result of an early prosthetic instability (due to insufficient initial fixation because of an inadequate interlock or of a weak cancellous bone bed, or due to loss of fixation because of resorption of a layer of heat-injured bone), and thus that "late loosening" is the result of late detection rather than of late occurrence of loosening. Some factors, such as body weight, physical activity, varus/valgus position, prosthetic neck length, etc., which have been implicated in epidemiologic investigations as important, probably only have a secondary influence on loosening (17). Finally, some proposed causes, including responses to wear products, metal sensitivity, stress-shielding, immunologic responses, etc., are probably results of loosening.

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