FEMORAL BONE LOSS IN TOTAL KNEE ARTHROPLASTY A REVIEW

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Femoral bone loss in total knee arthroplasty (TKA) is a common feature and is mainly attributed to three etiological factors. Stress shielding causes an "osteopenia" type of bone loss behind the anterior flange and adjacent to the distal aspects of the femoral component. Using dual-energy xray absorptiometry, decrease in bone mineral density up to 44% has been measured in these areas. Secondly, polyethylene, cement and metal particles are released by implant wear and may cause the less common "osteolysis" type of bone loss located directly at the anterior and posterior implant-cement-bone interfaces. This type of bone loss occurs mainly in young, male, overweight patients with osteoarthritis. Finally, implant loosening leads to bone loss at the bone cement-implant interface and results in "hollowing out" of the distal femur in a stemmed TKA. Femoral bone loss may be reduced by diminishing the stress-shielding effect, by improving the quality of the polyethylene insert, and by decreasing the rate of implant loosening still further. In revision TKA, femoral bone loss is often underestimated in the preoperative radiographs. Classification of bone loss should be made during surgery, and should be based upon the size of the defect generated and the grade of containment. The choice among cement filling, metal augmentation, custom-made TKA, solid bone grafts, and morsellized bone grafts in reconstruction of bone defects will depend upon the type of bone loss, the bone quality, the surgeon's preference and philosophy, and the availability of grafts and implants.

Keywords : total knee arthroplasty ; revision ; bone graft.
Mots-clés : prothèse totale de genou ; reprise ; greffe osseuse.

INTRODUCTION

The annual number of total knee arthroplasties (TKA's) performed worldwide continues to increase and has now exceeded 300,000. Revision TKA will occur more frequently in the future, and surgeons should be in the position to deal with this type of demanding surgery. Loss of bone stock in revision TKA is one of the most difficult problems to handle. The orthopedic surgeon must be familiar with reconstruction of bone defects because after removal of a femoral component, femoral bone stock deficiency is often greater than expected (35, 42). Many papers have been published on the issue of management of bone loss, in particular tibial bone loss, in TKA (2, 27, 44, 55, 56, 62). This review focuses on the etiology and management of femoral bone loss in revision TKA.

FEMORAL BONE LOSS

The three major factors contributing to femoral bone loss in TKA are discussed in the following paragraphs.

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1) Stress shielding

In the unreplaced knee, the anterior femoral condyles receive stress from the quadriceps muscle via the patella. When a femoral component is in place, the patellar pressure is not applied to the anterior condyles but is shielded by the implant and redistributed to the proximal bone-(cement-) implant interface. Radiographic follow-up of a TKA often reveals an area of osteopenia behind the anterior flange of the femoral component (fig. 1 a,b). In theory, there is an increased risk of periprosthetic fracture or component loosening at this site, especially in patients with rheumatoid arthritis (37). In practice, fortunately, these events are rare, and this type of bone loss usually occurs without symptoms (17).

A number of research groups have predicted stress shielding and subsequent femoral bone loss after TKA based on computer finite element models (3, 28, 52, 57). The greatest stress-shielding effect and bone loss were found at the most distal anterior area of the femur and behind the anterior flange of a bonded femoral component. Van Lenthe *et al.* (28) introduced a long-term prediction based on a strain-adaptive bone remodeling theory. They reported severe bone resorption in the same regions and the mid-distal femoral region when the femoral component was bonded to the bone. In the unbonded situation, bone loss was less extensive. This simulated process did not reach an equilibrium after 2 years, as was found in a radiographic study (8). The bone resorption was even greater when a thick, bonded stem was added to the femoral component (61). Histologic analysis of stress-shielded areas shows that overall the bone is vital with thin and scarce trabeculae (fig. 2a-e). At the bone-cement interface, direct bone-cement contact sites with non-mineralized woven bone are present and are interspersed with areas containing a thin soft-tissue interface.

In summary, distal mid- and distal anterior femoral bone resorbs in the presence of a femoral component because these regions are unloaded.

2) Wear

In contrast to the "osteopenia" type of bone loss seen in stress shielding, wear causes an "osteolysis" type of bone loss around apparently stable implants (54). Cadambi *et al.* described an 11% incidence of radiographic femoral osteolysis in uncemented TKA (6). Osteolysis is defined as the periprosthetic replacement of bone by chronic

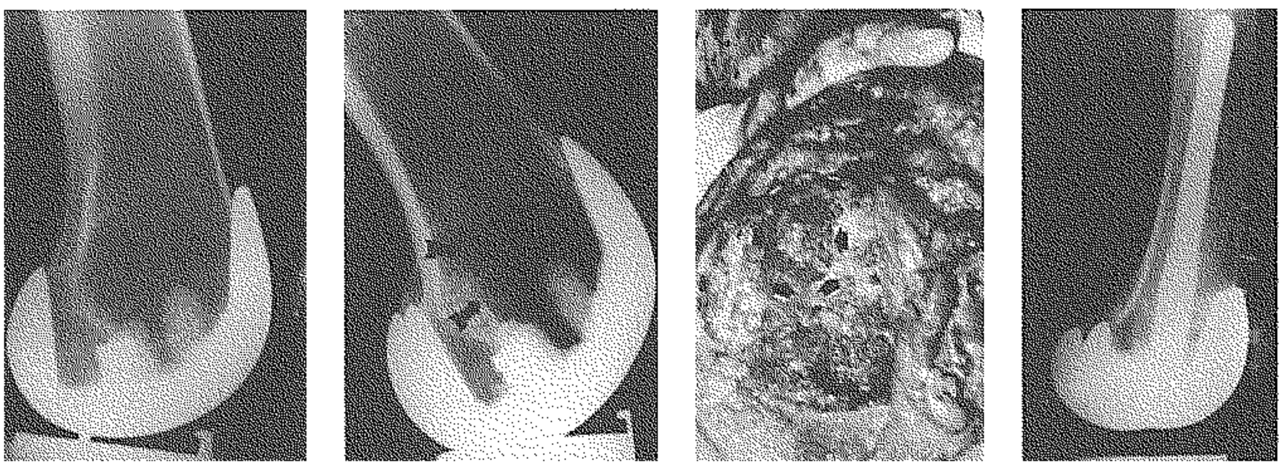

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Fig. 1. — ***a.*** Postoperative radiograph of a 49-year old female patient A after TKA for osteoarthritis. ***b.*** 12 years after implantation, an osteopenic area is visible behind the anterior flange of the femoral component in the follow-up radiograph (arrows). ***c.*** The TKA was revised and the bone defects were grafted with impacted cancellous bone grafts, and a revision femoral component was implanted. ***d.*** Intra-operative situation after removal of the femoral component : a large area behind the anterior flange is filled with soft bony tissue (arrows).

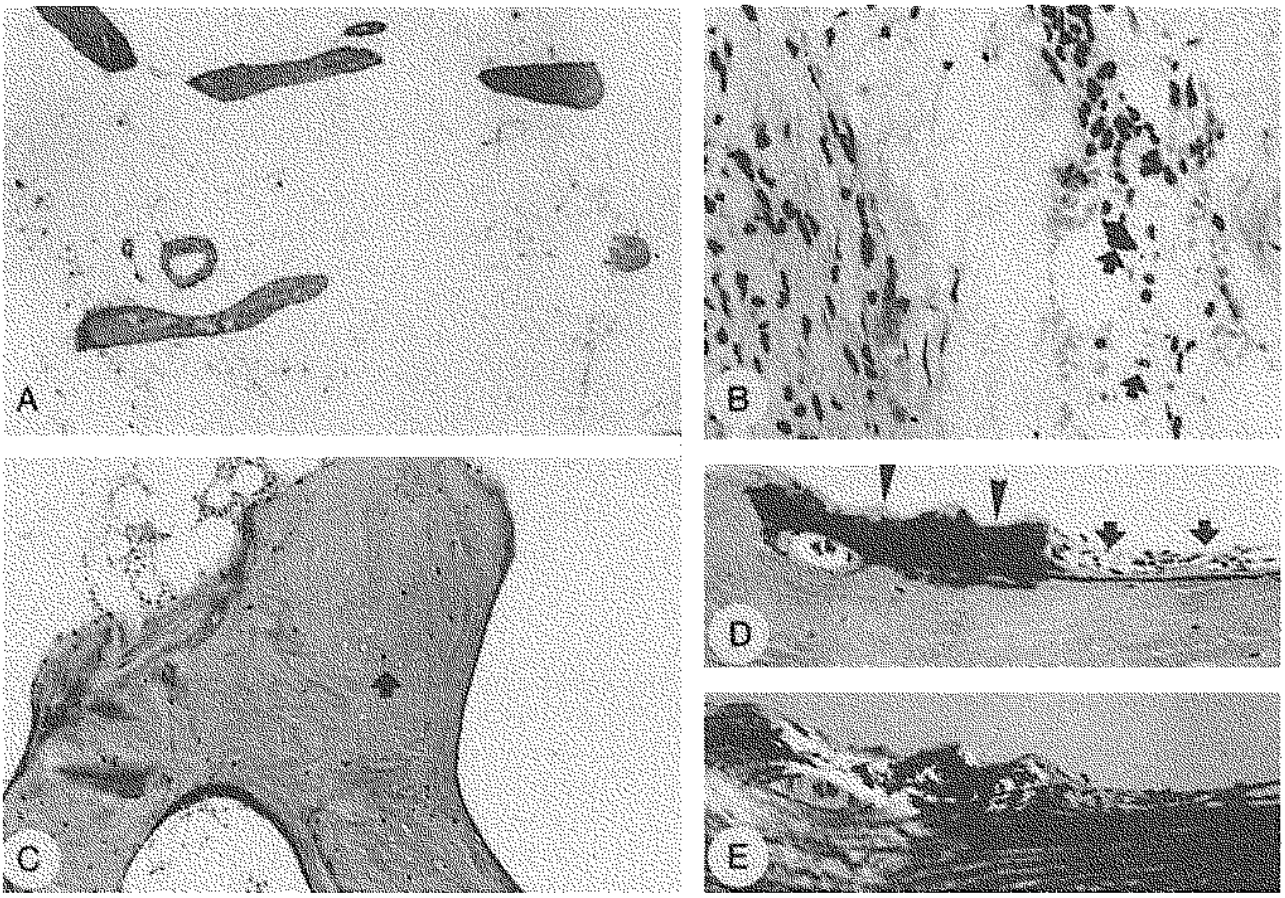

Fig. 2. — Biopsy of patient A (see fig. 1) at revision TKA. The biopsy was taken from the areas directly behind the anterior flange of the femoral component. ***a.*** Central part of biopsy showing thin, scarce trabeculae that are not interconnected with each other, surrounded by fat marrow (× 45). ***b.*** Area of relatively thick soft-tissue bone-cement interface with fibrous tissue and macrophages containing a few wear particles (arrows). Polarized light showed small polyethylene particles in some cells (not shown, × 360). ***c.*** Relatively thick trabeculae with a small area of necrotic bone (× 90). ***d, e.*** Thin soft-tissue interface between cement and bone (arrows), interspersed with areas of direct bone-cement contact and woven non mineralized bone (arrowheads, × 180).

inflammatory tissue without evidence of loosening (54). Macrophages phagocytose particles from bone cement, as well as polyethylene inserts and metal implants, and may differentiate into osteoclasts and thus cause osteolysis (33, 43). Bone disappears at the upper anterior flange and the posterior condyles. This type of bone loss is significantly more common in young, male, overweight patients with osteoarthritis (6). Since the mid-80's, cases of osteolysis as a result of polyethylene and metal wear have been reported in the literature (4, 9, 11, 23, 25, 58). Although the condition was first named "cement disease", polyethylene debris (particle size < 2 micron) is now thought to be the most important etiological factor (54). At present, polyethylene wear is considered to be the leading cause of TKA failure (25, 26). Thus, the polyethylene insert appears to be the weakest link in TKA. Robinson *et al.* revised 185 cemented and uncemented TKA's following aseptic loosening and found 17 TKA's with damaged polyethylene inserts, severe noncontained bone loss and foreign body reaction at the proximal tibia and distal femur in most cases (42).

Ezzet *et al.* reported more osteolysis in cementless femoral components compared to cemented femoral components (17). These findings suggest that a cement mantle could protect against the osteolysis type of bone loss.

3) Implant loosening

The first generation, hinged TKA's yielded unacceptably high loosening rates due to the high forces at the implant-cement-bone interface (7). If such a bulky implant became loose, the micromotions between the implant and the host bone resulted in enormous loss of bone stock. In cases of revised hinged prostheses, the distal femur had the shape of an "empty ice-cream cone" after removal of the prosthesis. Fortunately, the frequency of aseptic loosening of femoral components of unconstrained total condylar TKA's is less than one percent after 10 to 15 years (34, 38). Finite element studies predicted a decrease in bone loss by stress shielding around unbonded femoral components of total condylar TKA's compared to bonded components (28, 61). Sculco advised revision of a loosened TKA while failure is evolving to avoid even larger bone defects at a later date (48).

QUANTIFICATION OF BONE LOSS

Mintzer *et al.* observed osteopenia in the distal anterior femur in 68% of 147 TKA's on plain radiographs, independent of the type of fixation or implant design (31). They found progression up to 1 year. Cameron and Cameron observed progressive osteopenia at the anterior femoral condyles up to 2 years in almost all cemented TKA's, in particular in patients with rheumatoid arthritis (8). Since plain radiographs are inaccurate in estimating bone mineralization (20), bone loss is often underestimated on preoperative radiographs relative to the true bone loss found at revision surgery (14, 42). Dual-energy xray absorptiometry (DEXA) is a tool to quantitatively measure periprosthetic bone mineral density (BMD) without the disturbance of metal implants (41). In the presence of an intercondylar box, however, the most distal femoral BMD cannot be measured. In a DEXA-study of 28 females, Liu *et al.* found 6 to 12 months after TKA, a 7 to 27% decrease in BMD behind the anterior flange and directly above uncemented femoral components (29). Petersen *et al.* reported 1 year postoperatively, a 19% to 44% decrease in BMD of the distal femur in 29 uncemented TKA's (37). The greatest bone loss was observed in the first 3 months after surgery. The same author followed 8 patients after uncemented TKA for 5 years with DEXA and reported an average decrease of 36% of BMD behind the distal anterior flange of the femoral component (36). The decrease in BMD did not continue after 2 years.

CLASSIFICATION OF BONE LOSS

Osseous defects at the distal femur can be classified as contained or noncontained. A contained (cavitary or central) defect is a loss of metaphyseal cancellous bone with an intact cortex supplying containment for filling. A noncontained (segmental or peripheral) defect is a loss of cancellous bone, together with a significant loss of surrounding cortical support (51). De Waal Malefijt *et al.* classified sizes of bone defects as follows : small defects are less than 4 cm^3 and large defects are more than 10 cm^3 (56). Elia and Lotke described large femoral bone defects as greater than one cm in diameter and encompassing more than 50% of the femur (14). The classification of bone defects and treatment options in revision TKA by Engh and Parks (15) is the most practical system (table I).

MANAGEMENT OF FEMORAL BONE LOSS IN REVISION TKA

Revision TKA on the femoral side is a 3-step procedure : 1) removal of the femoral component (and cement), 2) preparation and reconstruction of the defects, and 3) placement of the revision femoral component.

Table I. — Classification and treatment options of femoral bone defects in revision TKA (15)

Type	Characteristics	Treatment
F1	Intact structural bone (contained, minor defects)	No need for stemmed or augmented components
F2A	Deficient unicondylar structural (noncontained) bone	Augmentation and bone grafts may be required
F2B	Deficient bicondylar structural (noncontained) bone	A stemmed component with augmentation (bone graft or metal) is required
F3	Severe structural (noncontained) bone loss with ligamentous instability	A custom or stemmed (collateral constrained) component with a bulk allograft is required

1) Removal of femoral component and cement

Careful implant removal is one of the most important factors in preserving bone stock in revision TKA (1, 48, 59). Special instrumentation and exposure with quadricepsplasty or tibial tubercle osteotomy are often necessary to adhere to the principles of preservation of bone (53). Alpert *et al.* even advocated division of the femoral component to reduce bone loss (1). However, even with careful handling, there will be loss of bone stock because the femoral component is often not loose (6, 46, 53). If the primary femoral component is malpositioned, it may be necessary to correct rotation by removing additional bone (30). Removal of a femoral component with an intercondylar box and stem will create large bone defects (1, 39, 45). Consequently, if a posterior stabilized or constrained TKA is to be implanted, this results in additional bone loss in the intercondylar area, and this entails the risk of a fracture (27). Cement should be removed with a cement chisel or Gigli saw at the prosthesis-cement interface ; levering, which could result in a condyle fracture, should be avoided (47). Whiteside advocated piecemeal removal of cement after fracturing of the cement mantle from the surrounding bone (59). In the area behind the anterior flange of the femoral component, the amount and quality of bone is often inferior due to stress shielding (fig. 1d).

2) Preparation and reconstruction of defects

During femoral bone preparation, a lavage system can be used to debride the surface and remove fibrous tissue (30, 48, 59). At this stage, the femoral bone defects should be classified (table I). There are several options for reconstruction of bone defects : cement filling, metal augmentation, custom-made TKA's, solid bone grafts, and morsellized bone grafts.

A) *Cement filling*

The primary function of cement is to supply component fixation. However, Scuderi and Insall (46), and Faris (18) advised filling small femoral defects of less than 5 mm with cement. In the recent literature femoral bone grafting is preferred to cement augmentation (32, 56).

B) *Metal augmentation*

Modular systems with metal augmentation are currently used in revision TKA. Bone defects of 5 to 10 mm can be treated by metal augmentation blocks (46). Metal inlays in various sizes can be attached to the distal and posterior parts of the femoral component of a posterior stabilized TKA with or without stem extension. This type of reconstruction may provide adequate initial stability and allow individual rebuilding of the condyles without further bone resection.

C) *Custom-made prostheses*

Custom-made TKA's can be successfully applied in the management of extensive noncontained femoral bone loss (40). Modification of the underlying bone is often necessary to improve the fitting of the prosthesis to the bone. The major drawbacks of this technique are high costs, manufacturing time, and imperfect fit (2, 48). Therefore, this technique should be reserved for difficult revision cases with the combination of extensive noncontained bone loss and ligamentous instability. Another indication for a custom-made TKA is a supracondylar periprosthetic femoral fracture (19). Less difficult revision cases can usually be treated with the current modular revision systems.

D) *Bone grafting*

Many surgeons favor bone grafting in the management of bone loss for reasons of economy, physiology, and versatility (13). The incorporation of bone grafts leads to restoration of bone stock and simplification of future revisions. In addition, bone grafting reduces the need for expensive custom-made TKA's and can be combined with metal augmentation or cement filling (48). Protected weight bearing should be prolonged for 3 months to 1 year until trabeculation of the bone graft is visible on the radiographs (59). Disadvantages of bone allografting are the limited availability, high costs, and possible transmission of infectious diseases.

Solid bone grafting

Noncontained femoral bone loss can be reconstructed by rebuilding a cortical rim with solid bone grafts to support the femoral component. Solid allografts are also used in cases of comminuted supracondylar fractures above a TKA, severe osteopenia, rheumatoid arthritis, and chronic corticosteroid medication (16, 24, 32, 35, 51). Fipp described a solid bone grafting technique, in which cement was first packed in the defect (21). The solid graft was then reshaped to correspond to the cement mold that was removed just before setting.

The results of solid bone grafting in TKA's are good at short-to-medium term follow-up. Ghazavi *et al.* reported an 85% success rate of massive femoral bone grafting in 20 knees at 3 years (22). Engh *et al.* reported 87% excellent or good clinical results of solid allografts and stemmed components after an average of 50 months (16). Long-term follow-up studies are unavailable at this time. Potential disadvantages are slow incorporation, disintegration, nonunion, and fracture of the solid grafts (5, 56, 59).

Morsellized bone grafts

Impacted morsellized cancellous bone grafts are currently used to fill smaller contained bone defects in TKA (51, 56, 59). In practice, morsellized grafts can easily be molded to fit uneven femoral bone defects. Adequate initial support may be improved by firmly impacting the graft. Ullmark and Hovelius (55) described a revision technique with impacted morsellized bone grafts in combination with a cemented stemmed TKA, similar to revision total hip arthroplasty (fig. 1c, 49). However, the initial stability after reconstruction of noncontained femoral bone loss with only morsellized bone grafts may be inadequate unless there is containment with a solid bone graft or metal mesh. The lack of soft-tissue coverage of the distal femur does not permit the application of metal meshes in this area. Revascularization of each morsel occurs, and bone formation is established throughout the graft (5, 49, 59). Cancellous grafts tend to repair completely with time, whereas cortical grafts remain as mixtures of necrotic and viable bone (5). Reconstruction of noncontained femoral bone loss with solely morsellized bone grafts has not been reported.

3) Placement of the revision femoral component

Soft-tissue balancing is essential in revision TKA and cannot be separated from the choice of implant (10). If soft-tissue laxity remains after reconstruction, a more constrained type of prosthesis should be used to provide stability (7, 47). When large structural allografts are used, a stemmed femoral component should be used to protect the graft (12, 16). Rotational alignment can be difficult in the presence of major bone loss, in particular of the posterior femoral condylar surfaces (59). Whiteside advocated determination of the rotational alignment of the femoral component relative to the anteroposterior axis (60). In a series of 40 revision TKA's with significant bone loss in which a combination of reconstruction options was used, 75% were considered excellent or good after 2 years (14).

DISCUSSION

Femoral bone loss in TKA appears to be a consequence of the arthroplasty. Stress shielding, wear, and implant loosening are factors that influence femoral bone loss ; these factors may be interrelated. The "osteopenia" type of bone loss, caused by stress shielding, fortunately does not cause major clinical problems. Van Lenthe *et al.* (28), using a finite element computer model, predicted less bone loss by stress shielding if a femoral component was unbonded, compared to the bonded situation. Therefore, in terms of reducing femoral bone loss, a loosened femoral component seems advantageous. Stern and Insall (50) advocated the routine use of stemmed components in revision TKA. Engh *et al.* used femoral stems mainly to protect large structural grafts in revision TKA (16). A finite element analysis has revealed that the predicted femoral bone loss is even greater in stemmed femoral components compared to stemless components (61). Predictions coming from finite element studies may have consequences for long-term results, so that perhaps the routine use of stems in revision TKA should be discouraged.

The "osteolysis" type of bone loss may be decreased by reducing the wear rate. Since the tibial polyethylene insert is the weakest part of the TKA, efforts should be made to improve the quality of the polyethylene. Nowadays, the use of tibial polyethylene components with a minimum thickness of 6 mm is generally advocated. Before wound closure, all free remaining cement should be meticulously removed to prevent third-body wear. On the issue of implant geometry, it may be advisable to enlarge the contact areas between the femoral component and the polyethylene insert in order to reduce peak contact stresses, even though a more constrained TKA may lead to a higher loosening rate.

Femoral bone defects can be reconstructed in various ways. The choice between cement, metal, or bone graft reconstruction depends on the type of bone defect, the bone quality, the surgeon's preference and philosophy, and the availability and costs of grafts and implants. In practice, cement filling and metal augmentation are only used in small bone defects in revision TKA. Bone grafting appears to be the biological solution, restoring what is missing. Structural bone grafting, often in combination with stemmed components, offers good results at medium-term follow-up, although graft failure remains a concern. The application of impacted morsellized bone grafts may be a viable option, given the success in revision total hip arthroplasty. The advantages in biological behavior compared to structural grafts may lead to a more widespread use of these grafts. However, noncontained femoral bone defects may be difficult to reconstruct without a supporting cortical rim or metal mesh. The initial stability may be insufficient to warrant its use in larger defects.

Future studies should be directed at validation of finite element models to ensure that the prediction of bone loss is realistic. In addition, well-designed experimental and clinical studies are required to enlarge our knowledge about the etiology and treatment of femoral bone loss in TKA.

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SAMENVATTING

C. J. M. VAN LOON, M. C. DE WAAL MALEFIJT, P. BUMA, N. VERDONSCHOT, R. P. H. VETH.
Femoraal botverlies in totale kniearthroplastie.

Femoraal botverlies bij totale knie prothesen is een veel voorkomend verschijnsel en wordt veroorzaakt door 3 factoren. „Stress shielding" veroorzaakt osteopenie achter het voorste deel van de femur component. Een afname van botdichtheid tot 44% op deze plaats is gemeten met dual-energy xray absorptiometrie. Polyethyleen-, cement- en metaal partikels ontstaan door slijtage en kunnen osteolyse veroorzaken aan de anterieure en posterieure overgang van prothese naar bot. Dit komt vooral voor bij jonge mannelijke artrose patiënten met overgewicht. Loslating van een implantaat kan leiden tot uitholling van het femur. Femoraal botverlies kan worden verminderd door het verbeteren van de kwaliteit van polyethyleen, het verminderen van „stress shielding", en het verder voorkomen van loslating van prothesen. Femoraal botverlies wordt preoperatief vaak onderschat op de röntgenfoto. Het botverlies dient preoperatief te worden geclassificeerd naar grootte en mate van afgrenzing. De behandeling van het botverlies

tijdens revisie totale knie-prothesen kan gechieden door opvulling met cement of metalen elementen, toepassing van „custum made" prothesen, toevoeging van solide of chip botgrafts. De keuze is afhankelijk van het type botverlies, voorkeur van de chirurg en beschikbaarheid van botgrafts en prothesen.

RÉSUMÉ

C. J. M. VAN LOON, M. C. DE WAAL MALEFIJT, P. BUMA, N. VERDONSCHOT, R. P. H. VETH. La perte de substance osseuse au niveau du fémur dans l'arthroplastie prothétique du genou.

La perte de tissu osseux fémoral après une arthroplastie totale du genou est un fait établi ; elle est principalement attribuée à 3 facteurs étiologiques. La déviation des contraintes entraîne une perte osseuse de type «osteopénique» derrière l'élément fémoral. Une diminution de densité osseuse allant jusqu'à 44% a été mesurée par absorptiométrie radiologique biphotonique. L'usure des componants prothétiques libère des particules de polyéthylène, de ciment et de métal qui peuvent causer une perte osseuse «ostéolytique» localisée aux interfaces avec l'os sous-jacent, en avant et en arrière. Ce type de perte osseuse se produit surtout chez des patients arthrosiques jeunes, de sexe masculin et obèses.
Le descellement prothétique mène à une perte de substance osseuse à l'interface ciment-os et par conséquent au «creusement» du fémur distal après arthroplastie totale avec une prothèse pourvue d'une tige intramédullaire. La perte de tissu osseux fémoral peut être réduite par la diminution du «stress shielding», par l'amélioration de l'insert tibial en polyéthylène et par une réduction du taux de descellement du matériel implanté. Dans les révisions d'arthroplasties totales du genou, la perte de tissu osseux fémoral est souvent sous-estimée sur les radiographies préopératoires. Une classification de la perte osseuse devrait être faite pendant l'intervention chirurgicale, en se basant sur les dimensions des défects observés et sur leurs caractères anatomiques (defects circonscrits, ouverts ou fermés). Les choix entre remplissage par ciment, augmentation métallique, recours a des prothèses sur mesure, greffes osseuses solides ou fragmentées pour reconstituer des défects osseux dépend du type de perte osseuse, de la qualité du tissu osseux, des préférences et de la philosophie du chirurgien et de la disponibilité d'implants et de greffes.