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Restoration of bone stock in revision surgery of the femur

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Abstract Three hundred and four femoral revisions were performed from 1987 to the end of 1990. All were done with cementless titanium calcar replacement prostheses, designed for proximal bone loading. Type III bone deficiencies were present in 160 femurs, all requiring supplemental cortical bone plates for bony augmentation. All grafts united and provided increased bone stock in the long term. Physiologic loading is important for graft remodeling and maturation. Hip scores have improved from an average Harris Hip Score of 44 to 84. Current survivorship at 10 years is 96%, and the revision rate is 3.2%. Thigh pain is mild in 3% of cases. There have been no late failures or distal lysis noted to date.

Résumé De 1987 à 1990, on a procédé à 304 reprises de prothèse totale de hanche (PTH) associées à des implants fémoraux standard en alliage de titane non cimentés et spécifiquement étudié et réalisés pour bien s'adapter à la morphologie osseuse et à la résistance mécanique proximale. 160 cas de fémur nécessitèrent – vu la présence de perte de sustance osseuse de type III – la mise en place sur la corticale de plaque osseuse de remplacement afin d'augmenter et la repousse fémorale osseuse. On observe dans les cas de reprise de PTH, une amélioraton du recul moyen: ce dernier passait de 44 mois (selon l'échelle de le Harris Hip score) à 84 mois. A l'heure actuelle, le taux actuariel de survie des implant est de 96% à 10 ans avec un taux de reprise de 3.2%. On note la presence de douleur à la cuisse dans 3% des cas, mais à l'heure actuelle, on ne rapporte aucun échec tardif ni osteolyse distale.

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Introduction

Femoral bone loss is most often the result of stress shielding and/or osteolysis. The ideal circumstance in revision surgery of the hip with a failed prosthesis on the femoral side is the creation of a stable implant, and the restoration and maintenance of lost bone stock [13]. This is best achieved with a proximal porous coated cementless titanium prosthesis, and when indicated onlay bone plate allografting [14,22]. The bone grafting procedure is indicated in type III femoral deficiencies with non-circumferential defects [4,26]. The grafts rapidly unite, revascularize and remodel. In order to enhance bone restoration long term, the grafts must be loaded physiologically [14]. This can thus be accomplished with an implant that transmits off-loading proximally. The deficient femur has the physiologic ability to repair itself as the result of proximal load bearing [14]. Freeze-dried cortical onlay grafts have been shown to reliably unite to the host bone and to provide increased bone stock [5,11,12,15]. With appropriate fixation and stresses, these grafts reliably unite, remodel, and provide bone mass in the long term.

Finite element studies have demonstrated that increased bone mass puts the prosthesis as well as the femur at decreased risk for fracture [22]. Increased bone mass sets the stage for a more reliable revision surgery, should that be necessary. Freeze-dried cortical bone struts are prepared by the technique of Malinin, and maintain bone morphogenic protein content, which in turn enhances bone union [2,25]. Titanium causes less stress shielding then does cobalt chrome, as it is approximately half as stiff [12]. Stems that are partially coated cause less stress shielding than fully coated stems. With a partially coated stem, there is more off-loading proximally than with an extensively coated stem [20,22]. Prosthetic stability is a major concern when a cementless implant is utilized. Therefore, implant design and extent of porous coating must be sufficient to adequately stabilize the prosthesis initially, and to provide potential for bony fixation in the long term. Wagner has presented

convincing clinical evidence of bone restoration with a titanium implant that depends upon diaphyseal fixation. However, subsidence and dislocation have been problems with this prosthesis [7,9,23,28,30,31,36–38]. There are times when the proximal femur is so structurally compromised that it has to be replaced with an oncologic prosthesis or a proximal femoral allograft [6,17,21,39].

Materials and methods

Biomechanical studies

Biomechanical studies analyzing off-loading patterns with calcar replacement titanium implants compared to intact femurs were performed on 6 anatomic specimens of cadaveric femurs. The same specimen was first loaded intact and then with a calcar prosthesis in place. Following strain energy density measurements, the specimens were stressed to failure in a torque mode.

Animal studies

Biomechanical properties of onlay bone plate allografts were studied in a canine model [2]. Bone plate allografts were placed over fresh fractures of the mid-portion of the radius produced by three-point bending. Each radius was then re-fractured at 2, 4, 8, 12, and 24 weeks post-transplantation. The force (expressed in Newtons) needed to re-fracture the radius treated with superimposed bone plates in various stages of healing was compared to that needed to fracture the intact, contralateral radius.

Histological studies

Biopsies and retrieved bone specimens have been studied from patients from 4 months to 6 years post bone grafting. Biopsies were obtained during acetabular revision surgeries. One specimen was retrieved at autopsy. Two specimens have been studied at revision surgery where struts were used below proximal femoral allografts. In these patients, specimens submitted for study were from the struts placed over the femur. The specimens were sectioned with a diamond blade saw fixed in 10% formalin-Earle’s balanced salt solution and decalcified in Pereney’s fluid. After dehydration and cleaning, the specimens were cut from paraffin blocks at 5 µm and stained with hematoxylin and eosin, Romanowski-Giemsa, and Masson’s trichsome stains.

Clinical studies

From 1987 through 1990, 434 cementless femoral revisions were carried out utilizing titanium calcar replacement prostheses (Mallory-Head Primary Press-fit Stem; Biomet; Warsaw, Ind., USA) (Fig. 1). Two hundred and nine of these patients received onlay cortical plate allografts. Prostheses for intertrochanteric fractures, proximal femoral allografts, and those in a hydroxyapatite study were not included in the present series in order to maintain uniformity of the sample. After eliminating cases with inadequate follow-up and patients who died or were lost to follow-up, 304 femoral revision cases (70% of the total) were left and available for evaluation.

The indication for the application of bone grafts were the class III femurs [4,26] with non-circumferential cortical deficiencies. The allografts were all freeze-dried and were prepared by the University of Miami Tissue Bank. The grafts were taken from the anterior tibia, and were excised and prepared under strict aseptic conditions according to the method described by Malinin [2]. The allografts were not subjected to treatment with alcohol or other chemical agents, nor were they subjected to irradiation. There were 160 type III femurs of this group (76%) to which cortical onlay graft augments were applied. Seventy-five percent of the grafts were proximal and medial, to cover bony deficiencies occurring most often in these locations. Grafts were placed both laterally and distally if cortical windows were utilized. Cortical grafts were also used to re-enforce an extended osteotomy repair [14].

Fig. 1 Calcar replacement porous coated prosthesis with a trans-fixing bolt and claw

All operations were performed in the lateral decubitus position, utilizing the revision technique described by Head et al. [16]. A viable muscle cuff of vastus lateralis and vastus intermedius is mobilized and covers the construct postoperatively. The cement and osteolytic tissue were removed from the femur by hand and power instruments. At times, anterior portals were created for better femoral visualization. Perioperatively, all patients received prophylactic antibiotics and all patients were given anticoagulant treatment postoperatively for prevention of deep vein thrombosis. Postoperatively, patients were maintained on partial weight bearing for approximately 3 months and then progressed to full weight bearing over the next 3–4 months. Patients were advised to use a cane or a crutch until the Trendelenburg gait was negative.

Results

Biomechanical studies

The proximal femur received 40% of load with a prosthesis in place, as compared to the intact specimen. The

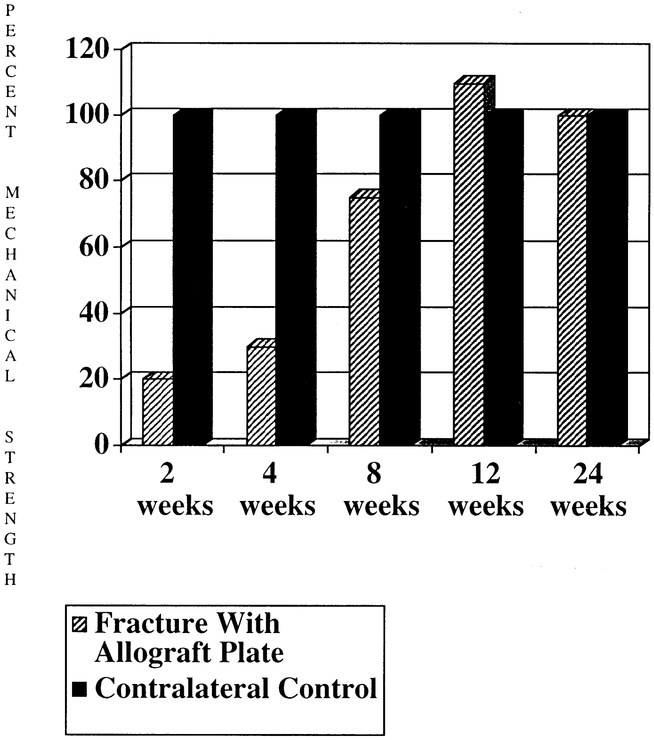


Fig. 2 Refracture of fractured radii with superimposed bone plate allografts: comparison of contralateral control radii

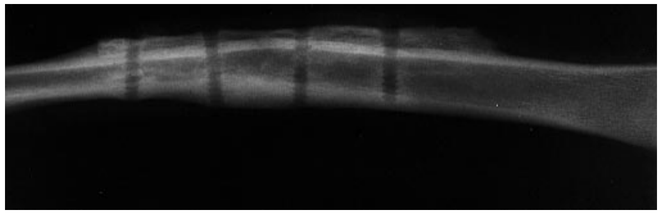


Fig. 3 Roentgenogram of a canine radius 8 weeks post-fracture with fixation with an onlay cortical plate allograft. The allograft has been revascularized, and is healed to the underlying bone. The allograft was held in place by cortical screws, which have been removed from the specimen

primary stabilizer to torque was the keel on the weight-bearing platform of the prosthesis. With an intact medial cortex and an accurately prepared notch for the keel, a transfixing bolt was the last failure mechanism safeguard. In the specimens with transfixing bolts in place, some of the stresses were transferred from the medial to the lateral cortex.

Animal studies

Bone plates contour to the bone. They also have the same modulus as the underlying bone. They do not inhibit external callus formation; however, bone plates become biomechanically weaker during the process of incorporation prior to regaining their full strength (Fig. 2). The data presented in Fig. 2 show that in 8 weeks, the fractured canine radius with an onlay cortical plate allograft has healed and regained a large percentage of its mechanical strength. A roentgenogram (Fig. 3) demonstrates a bone plate allograft superimposed on a fractured canine radius 8 weeks post-fracture.

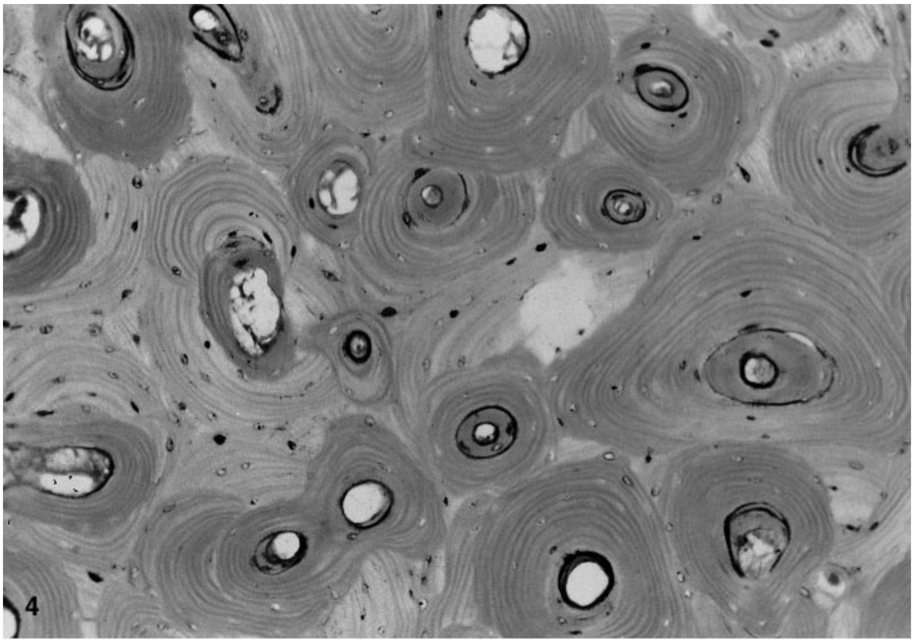
Histological studies

The incorporation and vascularization of the onlay bone plate allografts was not uniform. In the specimens from 4 months to 2 years post-transplantation, revascularization occurred along the pre-existing channels. The pattern of revascularization and new bone formation depended upon these areas within the allografts. New bone formation took place first on the surface of the graft and then at the host graft junction. In specimens 2 years and longer post-transplantation, the entire graft was revascularized and formation of new lamellar bone was noted throughout. Figure 4 is a photomicrograph from an area of such a bone plate allograft near the surface. Formation of new osteones with the lamellar bone is shown, as is the presence of new osteocytes in the lacunae. Figure 5 shows an area of the same bone plate near the host-graft junction. The bone here is more mature and repopulated entirely with osteocytes. All allografts over 2 years post transplantation were completely revascularized and contained new lamellar bone. Grossly, all bone plates were contiguous with underlying bone.

Clinical studies

The average preoperative score was 44. At current review, the average Harris Hip Score is 84 (range 70–90). At 10 years survivorship of this group of patients is 96%. Radiologic review reveals maintenance or enhancement of bone stock in all cases. There has been no dissolution of the grafts or loss of graft length, other than by rounding off at the ends. The grafts consistently go through the phases of union, revascularization, remodeling and maturation. The entire sequence takes 3–5 years, proceeding more rapidly on the compression side.

To date, there have been 10 revisions (3%). There were 2 revisions due to infection, 3 revisions due to implant instability, 3 revisions due to recurrent dislocation and 2 reoperations due to thigh pain because of modulus mismatch between prosthesis and bone requiring additional cortical grafting. Subsidence of 2 cm occurred in one revision case in which the prosthesis was rested on strut bone graft. Maximum subsidence was 2 mm when the prosthesis was supported by host bone. There were no perioperative deaths and no fatal pulmonary emboli. No significant intraoperative fractures occurred. Radiologic review indicated consistent prosthetic bone ingrowth with no evidence of distal lysis or impending failures. Some mild thigh pain was reported by 3% of patients, other than the 2 cases with modulus mismatch



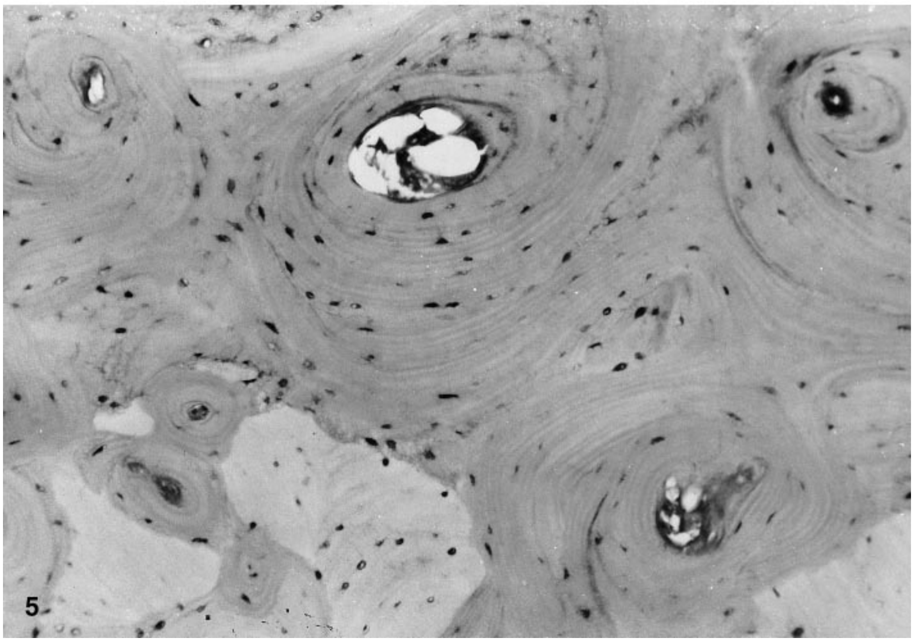


Fig. 4 Histological section of onlay cortical plate allografts, 2 years post-transplantation. The sample was taken near the surface of the plate. Note the formation of new osteones and lamellar bone around the pre-existing channels. Romanowski-Giemsa stain, ×100

Fig. 5 Microphotograph of an onlay cortical bone plate allograft at the host graft junction. The specimen is the same as in Fig. 3. In this portion of the graft, lamellar bone is mature and the lacunae contain viable staining osteocytes. Romanowski-Giemsa stain, ×100

requiring bone grafting. All cases in which bone plate allografts were applied demonstrated restoration of femoral bone stock long term with revascularization and remodeling of the graft [14].

Discussion

Cementless revision prostheses designed for proximal fixation have come under scrutiny as a result of high failure rates [1,29,32]. However, the designs of prostheses that have been unsuccessful were unlike the prostheses utilized in this group of patients. When implanted, the calcar replacement prosthesis is stable. Bone ingrowth further stabilizes the implant long term, while proximal load bearing enhances bone stock restoration in the femur [14]. Onlay bone plate allografts further enhance long-term bone restoration.

The calcar replacement design is not new. It was originally designed and utilized by Leinbach for comminuted intertrochanteric fractures [10,19,24,34,35]. However, his prosthesis was made of cobalt chrome and was used with cement. McLaughlin and Harris have reported on cemented calcar replacement prostheses in revision of failed hip arthroplasties, as have Clarke and Sim et al. [3,8,27,33]. The above-cited reviews do not contain information with regard

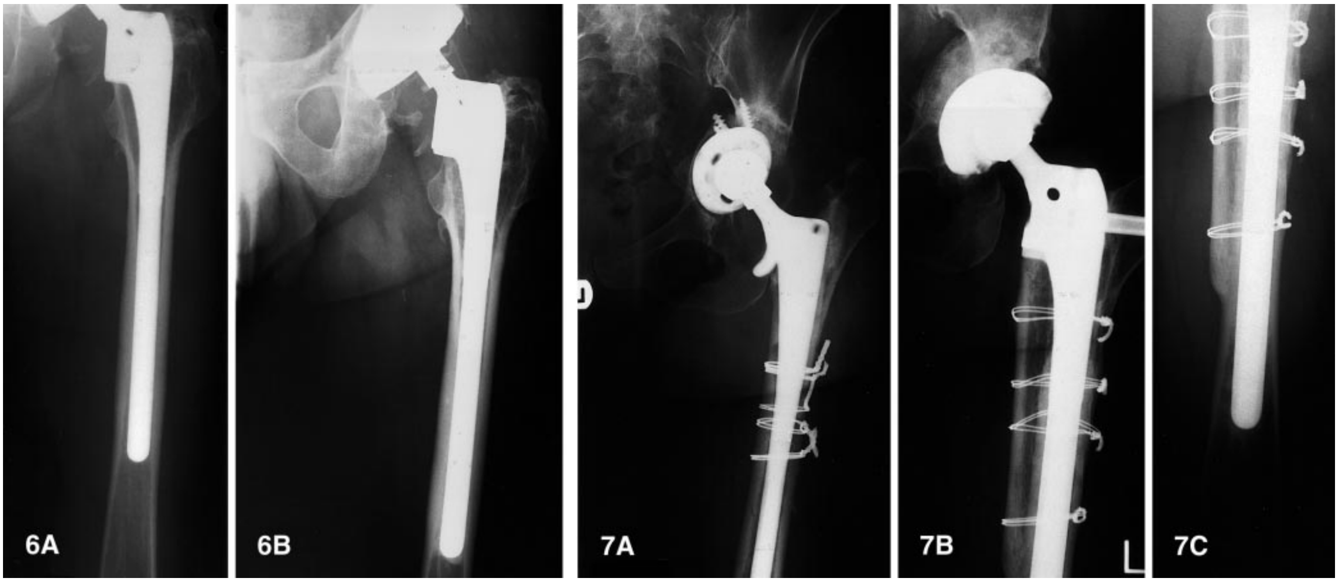


Fig. 6 **A** Postoperative X-ray at 2 years post-revision. **B** Postoperative X-ray at 10 years post-revision. Femoral bone enhancement has occurred and radiologic evidence of extensive bone ingrowth is present

Fig. 7 **A** Preoperative X-ray with a failed revision prosthesis in place. **B** Ten years postoperative X-ray demonstrating reestablishment of the proximal femur with an onlay allografts and a stable implant. **C** Distal portion of graft and prosthetic stem at 10 years post-surgery

to the use of bone graft augment or long-term results regarding femoral bone restoration or stress shielding.

It should be mentioned that in the biomechanical study, the prosthetic device was inserted in a press-fit line-to-line technique. It is entirely possible that bony ingrowth would alter the results of the study. However, the study is significant in that it demonstrates proximal femoral loading with a prosthetic device in place. This is further validated in the radiologic bony response with the prosthesis in place (Fig. 6). It is also validated by the very positive remodeling response of the femur with onlay grafts and the long-term bone enhancement of the femur (Fig. 7).

In order for prosthetic revision of the femur to be successful in the long term, the implant must be stable, bone stock must be maintained and/or restored, and a seal of the proximal femur must be accomplished. To date, the present prosthetic design has been successful in achieving these goals. In femurs with class III deficiencies, cortical onlay bone plate allografts consistently restore and maintain bone stock. There have been no complications as a result of the grafts. In order for the struts to provide femoral restoration in the long term, they must be stressed physiologically. To date, this has been a successful technique. In those cases not requiring grafts, proximal stress shielding has not been noted and bone enhancement frequently occurs.

References

1. Berry DJ, Harmsen MS, Ilstrup D et al. (1995) Survivorship of uncemented proximally porous-coated femoral components. Clin Orthop 319:168–177
2. Buck BE, Malinin TI (1994) Human bone and tissue allografts. Clin Orthop 303:8–17
3. Clarke HD, Sim FH, Damron TA et al (1999) Head and neck replacement prostheses in revision hip arthroplasty: experience with a single modern design. Orthopedics 22:313–318
4. D'Antonio A, McCarthy JC, Bargar WL et al (1993) Classification of femoral abnormalities in total hip arthroplasty. Clin Orthop 296:133–139
5. Emerson RH Jr, Malinin TI, Cuellar AD, Head, WC, Peters PCJR (1992) Cortical strut allografts in reconstruction of the femur in revision total hip arthroplasty. A basic science and clinical study. Clin Orthop 285:35–44
6. Gross AE, Hutchison CR (1998) Proximal femoral allografts for reconstruction of bone stock in revision arthroplasty of the hip. Orthop Clin North Am 29:313–317
7. Grunig R, Morscher E, Ochsner PE (1997) Three- to 7-year results with the uncemented SL femoral revision prosthesis. Arch Orthop Trauma Surg 116:187–197
8. Harris WH, Allen JR (1981) The calcar replacement femoral component for total hip arthroplasty: design, uses and surgical technique. Clin Orthop 157:215–224
9. Hartwig CH, Bohm P, Czech U, Reize P (1996) The Wagner revision stem in alloarthroplasty of the hip. Arch Orthop Trauma Surg 115:5–9
10. Harwin SF, Stern RE, Kulick RG (1990) Primary Bateman-Leinbach bipolar prosthetic replacement of the hip in the treatment of unstable intertrochanteric fractures in the elderly. Orthopedics 13:1131–1136
11. Head WC, Emerson RH Jr (1995) Freeze-dried cortical strut allografts for femoral reconstruction. In: Galante JO, Rosenberg AG, Callaghan JJ (eds) Total hip revision surgery. Raven, New York, pp 435–443
12. Head WC, Emerson RH Jr, Cuellar AD (1993) Cortical strut allografts for femoral reconstruction in revision hip arthroplasty. Seminars in Arthroplasty 4:9–15
13. Head WC, Wagner RA, Emerson RH Jr, Malinin TI (1993) Restoration of femoral bone stock in revision total hip arthroplasty. Orthop Clinics North Am 24:697–703
14. Head WC, Wagner RA, Emerson RH Jr, Malinin TI (1994) Revision total hip arthroplasty in the deficient femur with a proximal load-bearing prosthesis. Clin Orthop 298:119–126

15. Head WC, Malinin TI, Mallory TH, Emerson RH Jr (1998) Onlay cortical allografting for the femur. Orthop Clinics North Am 29:307–312
16. Head WC, Montgomery WK, Emerson RH Jr (1999) Vastus slide and controlled perforations. In: Zuckerman JD (ed) AAOS Instructional Course Lectures 48:13–17
17. Head WC, Emerson RH Jr, Malinin TI Structural bone grafting for femoral reconstruction. Clin Orthop (in press)
19. Heiman ML (1982) Leinbach prosthesis in unstable intertrochanteric fractures. Contemp Orthop 5:37–44
20. Huiskes R (1990) The various stress patterns of press-fit, ingrown, and cemented femoral stems. Clin Orthop 261:27–38
21. Johnson ME, Mankin H (1991) Reconstructions after resections of tumors involving the proximal femur. Orthop Clin North Am 22:87–103
22. Keaveny TM, Bartel DL (1995) Mechanical consequences of bone ingrowth in a hip prosthesis inserted without cement. J Bone Joint Surg [Am] 77:911–923
23. Kolstad K (1994) Revision THR after periprosthetic femoral fractures. An analysis of 23 cases. Acta Orthop Scand 65:505–508
24. Leinbach IS (1969) Prosthesis replaces entire hip joint. JAMA 207:1445–1446
25. Malinin TI, Latta LL, Wagner JL, Brown MD (1984) Healing of fractures with freeze-dried cortical bone plates: comparison with compression plating. Clin Orthop 190:281–286
26. Mallory TH (1998) Preparation of the proximal femur in cementless total hip revision. Clin Orthop 235:47–60
27. McLaughlin JR, Harris WH (1996) Revision of the femoral component of a total hip arthroplasty with a calcar-replacement femoral component. J Bone Joint Surg [Am] 78:331–339
28. Michelinakis E, Papapolychroniou T, Vafiadis J (1996) The use of a cementless femoral component for the management of bone loss in revision hip arthroplasty. Bull Hosp Joint Dis 55:28–32
29. Nourbash PS, Paprosky WG (1998) Cementless femoral design concerns. Rationale for extensive porous coating. Clin Orthop 355:189–199
30. Ponziani L, Rollo G, Bungaro P et al. (1995) Revision of the femoral prosthetic component according to the Wagner technique. Chir Organi Mov 80:385–389
31. Rinaldi E, Marenghi P, Valenti E (1994) The Wagner prosthesis for femoral reconstruction by transfemoral approach. Chir Organi Mov 79:353–356
32. Roberson JR (1992) Proximal femoral bone loss after total hip arthroplasty. Orthop Clin North Am 23:291–302
33. Sim FH, Chao EYS (1981) Hip salvage by proximal femoral replacement. J Bone Joint Surg [Am] 63:1228–1239
34. Stern MB, Angerman A (1987) Comminuted intertrochanteric fractures treated with a Leinbach prosthesis. Clin Orthop 218: 75–80
35. Stern MB, Goldstein TB (1977) The use of the Leinbach prosthesis in intertrochanteric fractures of the hip. Clin Orthop 128:325–331
36. Suominen S, Santavirta S (1996) Revision total hip arthroplasty in deficient proximal femur using a distal load-bearing prosthesis. Ann Chir Gynaecol 85:253–262
37. Wagner H (1999) Twelve years of cementless revision in retrospect Wagner self-locking revision stem and acetabular reinforcement cage. Int Orthop 23:1–6
38. Wagner H, Wagner M (1993) Femur revision prosthesis. Z Orthop Ihre Grenzgeb 131:574–577
39. Zehr RJ, Enneking WF, Scarborough MT (1996) Allograft-prosthesis composite versus megaprosthesis in proximal femoral reconstruction. Clin Orthop 322:207–223