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Modular, Mobile-Bearing Hinge Total Knee Arthroplasty

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Early reports of hinge total knee arthroplasty showed high rates of complications and implant failure. Third-generation modular, mobile-bearing, hinge knee arthroplasty systems have evolved to decrease the deleterious stresses that contributed to the failures of earlier designs. The combined series of Barrack et al and Jones et al documents midterm results using the S-ROM Hinge Knee System for patients with significant soft and hard tissue deficiencies not suitable for standard, less constrained, revision knee systems. The combined series included 30 knees with a mean followup of 49 months. Knee Society clinical scores improved from 52 to 134 points. There were no mechanical failures of the implants. The knee system used provides press-fit diaphyseal stems and metaphyseal filling and loading sleeves, all of which showed apposition and positive remodeling of bone at followup radiographic analysis. The excellent midterm results of this modular, mobile-bearing, linked knee system suggest the orthopaedic surgeon can display increasing confidence in the selection of such a knee system when confronted with catastrophic, salvage knee arthroplasty.

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For the majority of patients with significant deformity and instability who undergo revision knee arthroplasty, the increase in constraint provided by posterior-stabilized or constrained condylar total knee systems will provide adequate clinical function. However, there is a definite subset of patients with severe anatomic distortion in bone deficiency, soft tissue supporting structures, or both that require a linked prosthesis. These patients with extraordinary joint destruction usually undergo revision knee arthroplasty, but patients with posttraumatic arthrosis, complex primary total knee, and knee arthrodesis takedown all can benefit from hinged knee arthroplasty.

Constrained, linked knee arthroplasty has been used in numerous designs since the initial report of Walldius.[24] The early designs were used as primary knee replacements and in revision situations. They were characterized by unidirectional motion, articulation with direct metal-to-metal load transmission, minimal size selection, and flattened femoral trochlea regions (when present at all). These features resulted in high stresses across the implant-cement-bone interfaces, excessive particulate wear debris, poor implant to bone size matching, and significantly high rates of complications and implant failure.

Newer designs of hinged total knee implants based on increasing conformity and decreasing stresses by recognizing the link between gait kinematics that require rotation at the knee and long-term good functional results have been used clinically during the past decade. These, third-generation, mobile-bearing, linked total knee systems incorporate significant improvements to correct the design flaws apparent in the earlier iterations of hinge knee prostheses.

As reported by Accardo et al,[1] Noiles, an engineer with United States Surgical Corporation, originally patented the mobile-bearing knee prosthesis concept in 1976. A review of the history of the Noiles Hinged Knee Prosthesis and its evolution into the current S-ROM Modular, Mobile-Bearing Hinge Prosthesis (Depuy, Inc, Warsaw, IN) is instructive in understanding the interrelationship between prosthesis design, followup studies, and long-term clinical success.[1,3,14,23] The original Noiles Hinged Knee prosthesis had three major components: a metal femoral section cemented into the canal, a cemented polyethylene tibial sleeve, and a metal tibial stem inserted into the sleeve, joined by a metal hinge axle-yoke mechanism to the femoral component. The design allowed for 20° rotational arc in the tibial sleeve and flexion and extension.

Although early short-term reports were favorable,[1,10] a longer-term study by Shindell et al[23] highlighted failures that became apparent by an average of 32 months. Eighteen arthroplasties were done in 14 patients with the original design Noiles Hinge prosthesis. Only four patients had revision surgery. Only one size prosthesis was available for all the patients. The failures occurred largely in males who weighed more than 90 kg (200 lb), and in all the revisions with progressive subsidence of the femoral components. Additionally, the patients with complications had larger intramedullary canals producing mismatches between prosthesis fit and fill and causing greater strains on the cement-trabecular interfaces. The report of Kester et al[16] on the mechanical failure modalities of the Noiles Hinge prosthesis showed extensive wear on the polyethylene tibial components and consolidated the necessity of major design modifications.

The original Noiles Hinged Knee prosthesis now is obsolete. The changes made to the system in the late 1980s and the early 1990s have been extensive. The femoral component and the tibial tray of the current hinge are of a CoCr alloy. The femoral trochlea groove was deepened. The articulating surface on the top of the tibial tray and the inside of the stem receptor area are highly polished to provide a broad mobile surface for the ultrahigh molecular weight polyethylene tibial bearing component. The polyethylene tibial bearing congruently articulates with the medial and lateral femoral bearing surfaces and with an axle-yoke assembly. Therefore, inherent stability, load sharing through broad articulating surfaces to reduce high contact stresses, and accommodation to gait kinematics are achieved. This knee prosthesis system has the capacity to add modular Ti intramedullary sleeves and stems of varying sizes. This feature enhances metaphyseal and diaphyseal fit, fill promoting intramedullary load sharing, fixation into intact bone, and by passing stress risers in situations of bone deficiencies. The metaphyseal sleeves are stepped and textured allowing for the possibility of bone ingrowth. The stems are splined to enhance rotational stability and slotted to more closely match bone stiffness. Femoral augments are available to help better restore the joint line. The system is shown in Figures 1 and 2.

Barrack et al[3] and Jones et al[14] reported mid-term, excellent results with the S-ROM Modular, Mobile-Bearing Hinge prosthesis in patients with severe knee problems not amenable to treatment by super-stabilizer type, nonlinked knee systems. The current authors will review the experiences of Barrack et al and Jones et al with a modular, mobile-bearing hinged knee system, provide radiographic followup on an additional 26 patients, and include a review of another similar knee system.

MATERIALS AND METHODS

Retrospective reviews of two separate series of patients who received a modular, mobile-bearing

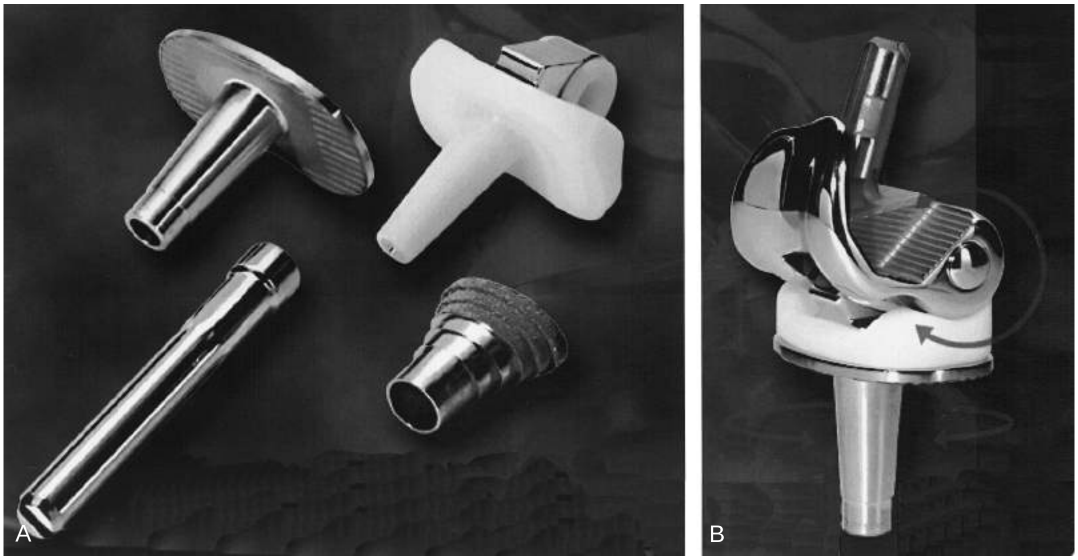

Fig 1A–B. The components, (A) exploded and (B) articulated, are shown.

hinge knee prosthesis were done by Barrack et al[3] (14 knees) and Jones et al[14] (16 knees). Both patient cohorts were consecutive and the operations were done by the senior authors. The hinged knee system was selected for patients with gross anatomic hard and/or soft tissue deficiencies that were judged to be beyond the capacity of nonlinked stabilized or constrained revision knee systems.

The surgical techniques were comparable. Previous skin incisions were used, prosthesis removal and debridement were done, and final assessment of bone loss and soft tissue support was done. The

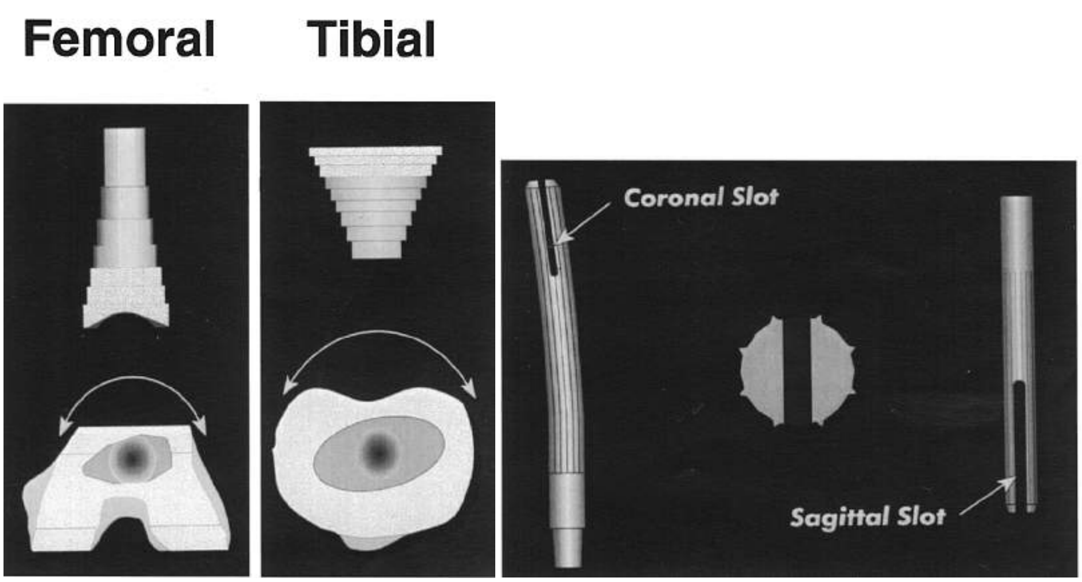

Fig 2. Femoral and tibial modular, diaphyseal stems, and metaphyseal sleeves are shown.

S-ROM intramedullary mounted instrument system provides for reaming the canal to size, broaching with sized medullary pilots to metaphyseal fill, and bone cuts made off the stem-sleeve aligned guides. In both series, antibiotic-impregnated cement applied to the condylar segments and press fit of the medullary stems were used. In the series of Barrack et al, additional cement was applied to the metaphyseal sleeves, whereas in the series of Jones et al, allograft bone chips were used to augment the large metaphyseal defects that were encountered.

Followup clinical and radiographic studies were done on all patients. The patients in the series of Jones et al[14] had Knee Society clinical scores,[11] Harvard Knee scores,[22] and visual analog scores for pain. The patients in the series of Barrack et al[3] had Knee Society clinical scores. Both patient groups had radiographic analysis according to Ewald[8] endorsed by the Knee Society. In the series of Jones et al, bone apposition and mechanical stability were assessed by the criteria of Engh et al[6] for evaluating the femoral and tibial components and the sleeve and stem regions.

Barrack et al[3] also compared clinical and radiographic data using the same methodology for patients who had total knee arthroplasty with a standard revision condylar component during the same period as the patients who had hinge knee revision arthroplasty.

Additionally, the current authors reviewed retrospectively the experience of Jones et al from June 1995 to June 1998 with the linked, modular knee system using the same operative technique and selection criteria. This review was a radiographic analysis only with the methodology described earlier. It included 26 patients and 26 knees with adequate available radiographs of 31 patients and 31 knees for the period. There were seven men and 19 women with ages ranging from 36 years to 82 years (mean, 63 years) with followup ranging from 24 months to 49 months (mean, 35 months). During this same period, 120 standard condylar revisions were done in patients with significantly less dramatic problems of bone loss or instability. Six of the knees were two-stage revisions for infected implants, two were revisions of hinged implants, and four modular hinges were used as primary implants, two of which were for knee arthrodesis takedowns. The remainder of knees were revisions of dramatic failures of primary total knee arthroplasty.

RESULTS

The demographic and knee data are shown in Table 1 for the series of Jones et al,[14] Barrack et al,[3] and the combined series of patients. Representative radiographs taken preoperatively and postoperatively are shown of one patient with reconstruction after knee arthrodesis for trauma and recurrent infection (Figs 3, 4) and of one patient who had conversion surgery from a failed Kinematic Rotating Hinge prosthesis (Fig 5).

Knee Function Measures

The patients in the series of Barrack et al[3] had an improvement in Knee Society clinical scores from a mean of 41 points to a mean of 131 points and an improvement in range of motion (ROM) from a mean of 78° to a mean of 93°. These results were compared with the results of patients who had less constrained condylar knee revision. These patients also had improved Knee Society scores from a mean of 81 points to 137 points and improved ROM from a mean of 92° to 101°.

The patients in the series of Jones et al[14] had an improvement of Knee Society clinical scores from a mean of 63 points to a mean of 137 points ($p < 0.001$), after excluding data from a patient with a postoperative traumatic patella tendon rupture who was medically unable to undergo operative repair. Range of motion in this group improved from a mean of 84° to a mean of 105° ($p = 0.0002$).

Visual analog pain scales showed significant improvement in walking (6.6 ± 2.2 preoperative versus 2.8 ± 3.0 postoperative; $p = 0.0001$) and stair climbing ability (7.6 ± 2.0 preoperative versus 3.9 ± 3.6 postoperative; $p = 0.0004$)

Radiographic Analysis

The patients in the series of Barrack et al[3] did not have progressive radiolucencies around femoral or tibial components and the alignment averaged 7° valgus built into the knee system. The patients with the modular hinge prosthesis had more severe bone loss according to the Engh classifica-

TABLE 1. Demographic and Knee Data

Series	Age	Gender	Component Revised	Previous Infection	Followup	Flexion Preoperative/Postoperative Mean	KSCS Preoperative/Postoperative Mean	Operative Time Mean
Jones et al[3]	33–83 years (mean, 63 years)	4 men 11 women	Hinge, 6 Other, 10	4	27–71 months (mean, 47 months)	84°–105°	63–137 points	<120 minutes
Barrack et al[14]	34–80 years (mean, 69 years)	8 men 6 women	Hinge, 7 Other, 7	0	24–74 months (mean, 51 months)	78°–95°	41–131 points	157 minutes
Combined	mean, 66 years	12 men 17 women	Hinge, 13 Other, 17 Total, 30	4	mean, 49 months	81°–100°	52–134 points	135 minutes

KSCS = Knee Society clinical score.

tion[7] than the patients with standard, less constrained condylar revision knee systems.

None of the patients in the series of Jones et al[14] had evidence of loosening or mechanical instability. One patient who was asymptomatic had a femoral anterior flange lucency, which progressed from 2 to 4 mm at 6 months, then remained stable. Three knees had 2 mm lucencies at the level of the proximal anterior femoral flange thought to be an imperfect surgical fit of the prosthesis in this area. At 6 months postoperatively these localized lucencies filled with bone. Diaphyseal stems and the metaphyseal sleeves were press fit in all patients. Radiographic analysis showed bone apposition to all the modular stems and sleeves, except in one patient with cement added on a tibial sleeve for bone deficiency treatment. No bone-implant interface radiolucencies of the sleeves or stems were identified.

The additional retrospective radiographic review of the 26 knee arthroplasties done from 1995 to 1998 correlated very closely with the earlier series from August 1991 to May 1995. Radiographic evidence of loosening or mechanical instability was not identified. There were two nonprogressive lucencies at the anterior femoral flange seen during the initial postoperative evaluation. Again, all the knees had press-fit femoral and tibial sleeves and stems and showed bony apposition and no implant-interface radiolucencies. Marchant views showed congruent femoral trochlear patella positioning in 25 knees with minimal patella subluxation in one knee.

Complications

Intraoperative fractures occurred during canal preparation in the femoral metaphysis in one patient in the series of Barrack et al[3] and in a femur and a separate tibial metaphysis in a patient in the series of Jones et al.[14] All patients were treated by cerclage wire or cable fixation and the intramedullary rods that are part of the implant construct. No changes in postoperative treatment were necessitated because of the stable constructs achieved.

Barrack et al[3] reported one patella subluxa-

Fig 3A–B. (A) Anteroposterior and (B) lateral radiographs of a 39-year-old man, 236 lbs, were obtained 1 year after knee arthrodesis for trauma and infection.

Fig 4A–B. (A) Anteroposterior and (B) lateral radiographs were obtained 30 months after knee fusion conversion to a modular mobile hinge prosthesis. The patient's range of motion was 0° to 105°.

tion for which the patient was treated by reoperative alignment. Also, one 5-mm axle migration occurred that was seen at 1 year and had not progressed at 6 years.

Jones et al[14] described one patient with two episodes of traumatic patella tendon ruptures. The first was repaired, but medical deterioration prevented a second repair. The patient

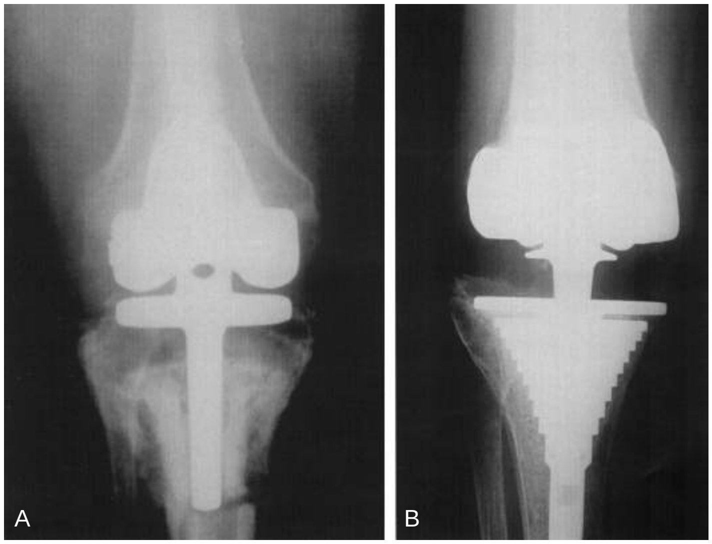

Fig 5A–B. Anteroposterior radiographs were obtained (A) preoperative and (B) 54 months postoperative of a 64-year-old woman, 290 lbs, with a failed Kinematic Rotating Hinge prosthesis. Radiographs obtained after surgery show bone apposition to stepped, textured, metaphyseal sleeves.

ambulated with a drop-lock brace. Another patient with Type-C host-healing capacity[5] had a recurrent infection develop and had resection arthroplasty. Neither series cited any mechanical failures of the prostheses or the modular links to sleeves or stems.

DISCUSSION

The stability inherent in linked total knee systems only is required occasionally, because nonlinked stabilizer or super-stabilizer (CCK-type) implant systems usually can suffice. Previous reports on the standard condylar revision implants[17,19] have cited superior results to those reported using first- or second-generation linked systems. The high complication rates and inconsistent outcomes seen with earlier and some currently available hinge-type prostheses have led many orthopaedic surgeons to view hinged knee arthroplasty with skepticism.

The first-generation hinge systems included the Walldius,[2,24,28] the GUEPAR,[12] and the Shiers,[25] and were metal-on-metal linked. These components had high stress transfer and particulate debris generation. Designs that decreased the constraint at the articulation evolved including the Herbert,[21] the Spherocentric,[18] and the Kinematic Rotating Hinge,[20] all of which continued to have unacceptably high complication rates and failures. The Noiles Rotating Hinge prosthesis was another second-generation system, but it also manifested major complications.[16,23]

More recently, third-generation modular, mobile-linked knee systems have been developed with advanced design features to address previous concerns. The S-ROM Modular, Mobile-Bearing Hinge Prosthesis cited in the current study incorporates: (1) 7° physiologic valgus, fixed in the femoral component; (2) deepened femoral trochlea groove; (3) modular textured sleeves to accommodate bone defects of the Engh Type II and Type III classification and allow for possible bone ingrowth; (4) splined and slotted tibial and femoral diaphyseal stems to enhance torsional stability and fixation into intact medullary bone; (5) broad, congruent contact areas between femoral and tibial components to best distribute surface and subsurface stresses in the polyethylene; (6) rotating hinge that accommodates axial rotation reducing stresses at the bone-cement-implant interfaces; and (7) selection of sizes to match condylar, metaphyseal, and diaphyseal anatomy and provide fit and fill of hard tissue.

It is suggested that these improvements in component design account for the low incidence of radiolucencies about the implant and positive outcomes reported in these studies.[3,14]

The Finn Knee is another evolved modular, rotating hinge system with encouraging early to mid term results. Kawai et al[15] reported on 32 rotating hinge knee segmental replacements for malignant tumors about the knee. The age range of the patients was 12 to 71 years (mean, 31 years), and the followup period was 24 months to 75 months (mean, 37 months). Twenty-five patients had distal femoral replacement, whereas the remainder of patients had proximal tibia segmental replacement. Most femoral stems were press fit in younger patients and cemented in older patients. The tibial stems were fixed similarly. Kawai et al[15] reported four component failures at the axle-yoke mechanism seen at an average of 29 months. The yoke housing of the hinge component was thickened 50% in 1995 and no failures were seen in subsequent knees.

Westrich et al[26] recently published another series of patients treated with the Finn Rotating Knee prosthesis. The implant was used as a primary prosthesis in nine patients and during revision surgery in 15 patients. The patients ranged in age from 16 to 93 years (mean, 63 years) and the followup was from 21 months to 62 months (mean, 33 months). This group of patients had pressure-cemented femoral and tibial stems in all but one instance when a 250-mm femoral stem was press fit. Westrich et al[26] also analyzed the clinical results by categorization according to Knee Society criteria[11] of asymptomatic versus symptomatic contralateral knee and multiple arthritides or systemic disease (A, B, and C, respectively). All patients had significant improvement in Knee Society scores. Patients in Category A and Category B had significant improvement in Knee Society functional scores, but the patients in Category C did not have significant functional improvement. Five of the 24 knees were revisions done for infected implants. Radiographic analysis showed two knees with progressive radiolucent lines and five knees with patella subluxation graded as slight but asymptomatic. Complications included one intraoperative femur fracture and one late femoral stress fracture.

The series of Jones et al[14] and Westrich et al[26] included revisions for implant infection in four of 16, and five of 24 knees, respectively. The radical debridement necessary to remove infected tissue often yields significant residual hard and soft tissue deficiencies. The patients with infected knee replacements in the series of Jones et al were treated according to a previously published two-stage protocol using antibiotic-impregnated cement and beads with an articulating implant composite.[4] There were no differences in results between the patients with infected knee replacements and patients without infected knee replacements.

The complex total knee arthroplasty procedures documented in the current review highlighted the use of press-fit diaphyseal filling stems. Other outcome studies[9,13,27] have supported this technique with reports of good to excellent results in revision total knee arthroplasty. Additionally, the S-ROM Modular Knee System provides sleeves that fit and fill the large Engh Type II and III bony defects often seen in salvage knee replacements. Therefore, the patients in the series of Jones et al and Barrack et al did not require bulk allograft reconstruction, enhancing operative time efficiency. The near complete absence of radiolucencies in the combined series suggests that the modular stems and porous-coated sleeves allow for clinically beneficial bone remodeling at the bone-implant interfaces.

When comparing the operative times in the studies of Barrack et al, Jones et al[14] and Westrich et al,[26] it is apparent that the intramedullary-mounted instrument system and availability of modular sleeves in the S-ROM System was advantageous. Westrich et al[26] reported operative time ranges for the Finn System of 150 to 340 minutes (mean, 198 minutes); Barrack et al cited a range of 100 to 190 minutes (mean, 157 minutes); and Jones et al reported 15 of 16 knee revision surgeries were completed with bulky compressive dressings applied before tourniquet release at 120 minutes.

The studies of modular, mobile-bearing

hinged knee systems reported herein suggest that the orthopaedic surgeon confronted with a catastrophic, salvage knee arthroplasty can display increasing confidence in the selection of a modular, mobile-bearing hinge knee system. The rare occurrences of radiolucencies reported in these studies suggest that the third-generation linked knee systems with dynamic, bipolar motion at the tibiofemoral articulation are sufficient to decrease the deleterious stresses that contributed to the failures of earlier designs of hinged knee systems. Additional followup is warranted to determine the long-term success of the currently extant systems.

References

1. Accardo NJ, Noiles DG, Pena R, et al: Noiles total knee replacement procedure. Orthopedics 2:37–45, 1979.
2. Bain AM: Replacement of the knee joint with the Walldius prosthesis using cement fixation. Clin Orthop 94:65–71, 1973.
3. Barrack RL, Lyons TR, Ingraham RQ, et al: The use of modular rotating hinge component in salvage revision total knee arthroplasty. J Arthroplasty 15:858–866, 2000.
4. Cadambi A, Jones RE, Maale GE: Antibiotic-cement-implant composites: A protocol for staged revision of infected total hip and knee arthroplasties. Orthopedics 3:133–145, 1995.
5. Cierny G, Mader J: Clinical staging for adult osteomyelitis. Contemp Orthop 10:15–18, 1985.
6. Engh CA, Massin P, Suthers KE: Roentgenographic assessment of the biologic fixation of porous-surfaced femoral components. Clin Orthop 257:107–128, 1990.
7. Engh GA: Bone Defect Classification. In Engh GA, Rorabeck CH (eds). Revision Total Knee Arthroplasty. Baltimore, Lippincott Williams & Wilkins 63–120, 1997.
8. Ewald FC: The Knee Society total knee arthroplasty roentgenographic evaluation and scoring system. Clin Orthop 248:9–12, 1989.
9. Haas SB, Insall JN, Montgomery W, et al: Revision total knee arthroplasty with use of modular components with stems inserted without cement. J Bone Joint Surg 77A:1700–1707, 1995.
10. Holt Jr EP: Use of the Noiles knee prosthesis in advanced disease. Orthop Trans 5:467, 1981.
11. Insall JN, Dorr LD, Scott RD, et al: Rationale of the Knee Society clinical rating system. Clin Orthop 248:13–14, 1989.
12. Jones EC, Insall JN, Inglis AE, et al: GUEPAR knee arthroplasty results and late complications. Clin Orthop 140:145–152, 1979.
13. Jones RE: Management of the bone-deficient knee: Management of complex revision problems with a modular total knee system. Orthopedics 19:802–806, 1996.
14. Jones RE, Skedros J, Harkins P, et al: Total knee arthroplasty using the S-ROM mobile-bearing hinge prosthesis. J Arthroplasty 16:279–287, 2001
15. Kawai A, Healey JH, Boland PJ, et al: A rotating-hinge knee replacement for malignant tumors of the femur and tibia. J Arthroplasty 14:187–196, 1999.
16. Kester MA, Cook SD, Harding AF, et al: An evaluation of the mechanical failure modalities of a rotating hinge knee prosthesis. Clin Orthop 228:156–163, 1988.
17. Lachiewicz PF, Falatyn SP: Clinical and radiographic results of the Total Condylar III and Constrained Condylar total knee arthroplasty. J Arthroplasty 11:916–922, 1996.
18. Matthews LS, Goldstein SA, Kolowich PA, et al: Spherocentric arthroplasty of the knee: A long-term and final follow-up evaluation. Clin Orthop 205:58–66, 1986.
19. Peters CL, Hennessey R, Barden RM, et al: Revision total knee arthroplasty with a cemented posterior-stabilized or constrained condylar prosthesis. J Arthroplasty 12:896–903, 1997.
20. Rand JA, Chao EY, Stauffer RN: Kinematic rotating-hinge total knee arthroplasty. J Bone Joint Surg 69A:489–497, 1987.
21. Ritter MA: The Herbert total knee replacement: A longer than three year follow-up. Clin Orthop 129:232–235, 1977.
22. Shaw JA, Balcom W, Greer RB: Total knee arthroplasty using the kinematic hinge prosthesis. Orthopedics 12:647–654, 1989.
23. Shindell R, Neumann R, Connolly JF, et al: Evaluation of the Noiles hinged knee prosthesis: A five-year study of seventeen knees. J Bone Joint Surg 68A:579–585, 1986.
24. Walldius B: Arthroplasty of the knee using an endoprosthesis: 8 years' experience. Acta Orthop Scand 30:137–148, 1960.
25. Watson JR, Wood H, Hill RCJ: The Shiers arthroplasty of the knee. J Bone Joint Surg 58B:300–304, 1976.
26. Westrich GH, Mollano AV, Sculco TP, et al: Rotating hinge total knee arthroplasty in severely affected knees. Clin Orthop 379:195–208, 2000.
27. Whiteside LA: Cementless revision total knee arthroplasty. Clin Orthop 286:160–167, 1993.
28. Wilson FC, Venters GC: Results of knee replacements with Walldius prosthesis. Clin Orthop 120:47–53, 1976.