Prosthetic Replacement of the Knee and a Large Segment of the Femur or Tibia*

BY FRANKLIN H. SIM, M.D.†, AND EDMUND Y. S. CHAO, PH.D.†, ROCHESTER, MINNESOTA

From the Mayo Clinic and Mayo Foundation, Rochester

ABSTRACT: **Total replacement of the knee and of a long segment of the femur or tibia provided functional recovery of the knee joint in thirteen patients in whom the length of the bone replaced ranged from seventy-five to 150 millimeters. Nine patients had benign bone tumors, three had malignant lesions, and one patient had salvage of a failed total knee arthroplasty associated with loss of bone structure. After follow-up of two years or more, all patients had a stable extremity, excellent relief of pain, and a useful range of motion, although one patient required revision for loosening.**

A radical *en bloc* resection may be necessary to eradicate a malignant or an aggressive benign tumor, and one that compromises the integrity of the knee joint poses a special problem[3]. The malignant lesions that can be effectively treated by *en bloc* resection — particularly chondrosarcoma, parosteal osteosarcoma, and low-grade malignant giant-cell tumor[1] — in the past did not permit effective salvage of the knee joint, but the availability of custom-made joint implants has opened up new horizons in that regard.

The present paper is a report on twelve such cases, and an additional case in which a failed total knee prosthesis posed a similar problem which was solved in the same way.

Clinical Material and Results

Since September 1974, we have treated twenty-five patients (fourteen male and eleven female; age range, fourteen to sixty-eight years) with total knee replacement, utilizing a special prosthesis for the segmental replacement of part of the femur or tibia plus the knee. Twelve of the twenty-five procedures were performed because of malignant tumors. We are describing our clinical experience with thirteen of these patients (six male and seven female) who have been followed for more than two years (average, thirty months) (Table I). Ten patients had involvement of the distal end of the femur and three had involvement of the proximal end of the tibia. The length of the replacement ranged from ten to 15.5 centimeters for the femur (average, 11.9 centimeters) and from 7.5 to eleven centimeters for the tibia (average, 9.5 centimeters). Of the thirteen patients, eight had giant-cell tumors (Figs. 1-A through 1-D); one, an aneurysmal bone cyst; one, chondrosarcoma; one, Ewing's sarcoma (Figs. 2-A through 2-D); one, fibrosarcoma; and one had the procedure performed because of a failed Buchholz total knee arthroplasty (Figs. 3-A, 3-B, and 3-C).

Of the thirteen patients who were studied, final follow-up showed one with moderate discomfort, and then only with increased activity. This patient (Case 1) had roentgenographic evidence of loosening of the femoral component thirty months after the resection and had a revision operation, which was successful. Three months after the revision, she was using a cane. The patient with Ewing's sarcoma (Case 9) remained active and asymptomatic for nearly two years, but then she sustained a pathological fracture of the femur because of local recurrence of the tumor. She had only mild discomfort, used crutches, and was receiving chemotherapy twenty-eight months after the resection.

Two patients used a cane, Cases 1 and 13. Case 13, with a failed Buchholz total knee replacement, had no symptoms referable to the procedure, but he used a single crutch because of gonarthrosis of the opposite knee. The average arc of motion in this group of patients was 87.6 degrees, and only three patients had a slight extensor lag.

Five of the thirteen patients had a two-stage operation. First, we resected the osseous lesion and inserted a temporary spacer consisting of methylmethacrylate. The delayed reconstruction with the custom-made total knee arthroplasty was done six to twelve weeks later. We have discontinued the two-stage technique because these five patients lost too much strength in the quadriceps and hamstring muscles from the long period of immobility. However, the ranges of motion improved with time, the average arc of motion for the knees of these five patients being 80 degrees.

None of the patients had any local wound complications. One patient (Case 7) required resection of a soft-tissue recurrence of a giant-cell tumor two months after the total knee replacement.

Gait and associated daily activities were chosen as criteria for evaluation to assess the functional deficits of the replaced joint. We also were able to continuously monitor the functional improvement biomechanically, and in that way we could detect early mechanical and clinical

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† Mayo Clinic, 200 First Street, S.W., Rochester, Minnesota 55901. Please address reprint requests to Dr. Sim.

TABLE I

CLINICAL MATERIAL AND FUNCTIONAL EVALUATION IN THIRTEEN PATIENTS WITH SEGMENTAL PROSTHETIC REPLACEMENT OF THE KNEE

Case	Sex, Age (*Yrs.*)	Diagnosis*	Bone Resected (*cm*)	Follow-up (*Mos.*)	Range of Motion (*Degrees*)	Biomechanical Indices†		
						Ipi	Ipt	Is
1	F, 28	Fibrosarc.	Femur, 14	30	0 to 100	8.08	6.79	0.74 (14)
2	M, 23	GCT	Tibia, 7.5	28	−5 to 90	4.19	1.09	0.73 (6)
3	F, 50	GCT	Femur, 10	40	0 to 100	2.87	0.00	0.89 (12)
						3.10	1.25	0.87 (24)
4	F, 63	CS	Femur, 15.5	36	0 to 50	11.18	4.56	0.63 (2)
						5.10	4.78	0.82 (16)
						4.13	2.43	0.88 (21)
5	F, 26	GCT	Tibia, 11	30	0 to 90	6.67	5.35	0.77 (6)
						3.20	2.18	0.83 (30)
6	M, 34	GCT	Femur, 11	33	0 to 100	4.37	4.87	0.84 (5)
						4.17	3.83	0.88 (14)
						5.42	5.20	0.89 (26)
7	M, 31	GCT	Femur, 11	26	0 to 90	5.84	1.81	0.67 (2)
8	F, 41	GCT	Femur, 10.5	28	0 to 100	10.11	3.00	0.54 (2)
						7.30	3.59	0.86 (6)
						4.84	0.11	0.74 (12)
9	F, 17	ES	Femur, 15	28	0 to 90	4.75	1.57	0.74 (8)
10	F, 14	ABC	Femur, 10	29	0 to 90	4.85	2.11	0.74 (8)
						−0.60	−1.11	0.75 (14)
						−0.81	0.96	0.70 (24)
11	M, 28	GCT	Femur, 12	40	−5 to 70	6.09	3.00	0.75 (8)
						4.39	1.46	0.74 (13)
						3.36	0.72	0.76 (20)
12	M, 22	GCT	Femur, 11	28	0 to 90	—	—	—
13	M, 44	Arth	Tibia, 10.5	26	−5 to 95	—	—	—

* GCT = giant-cell tumor; CS = chondrosarcoma; ES = Ewing's sarcoma; ABC = aneurysmal bone cyst; and Arth = arthritis (failed prosthesis).

† Ipi = involved side; Ipt = contralateral side; Is = symmetry index (see text); and the numbers in parentheses represent the number of months after operation when the biomechanical indices were obtained.

FIG. 1-A

FIG. 1-B

Figs. 1-A through 1-D: Case 3.

Figs. 1-A and 1-B: Anteroposterior and lateral roentgenograms of the knee, showing extensive giant-cell tumor of the distal end of the femur.

FIG. 1-C

FIG. 1-D

Anteroposterior and lateral roentgenograms of the right knee, showing segmental total knee arthroplasty thirty-eight months after operation.

complications. The method also permitted the quantitation of the kinematic and kinetic information for subsequent determination of prosthetic joint forces and moments and the establishment of an optimum exercise program in order to compensate for the inherent weakness of muscle deficiency and to prevent possible abuse of the implant.

Of the thirteen patients, all of whom were followed for more than two years, eleven have been evaluated in our Biomechanics Laboratory at various postoperative periods. The results of these evaluations in terms of the indices that we devised are included in Table I.

All the patients who were studied had normal motion patterns and no detectable limp. Typical tracings from a patient whose right knee was replaced by a custom-made prosthesis are shown in Figure 4.

In order to provide objective comparison of the gait-evaluation data among the patients with segmental prostheses, two functional indices derived from nine of the most significant gait parameters were used in the present study: passive flexion of the knee, standing flexion of the

FIG. 2-A

FIG. 2-B

FIG. 2-C

FIG. 2-D

Figs. 2-A through 2-D: Case 9, a seventeen-year-old girl with Ewing's sarcoma.
Figs. 2-A and 2-B: Anteroposterior and lateral roentgenograms of the distal end of the right femur, showing a pathological fracture.
Figs. 2-C and 2-D: Anteroposterior and lateral roentgenograms showing segmental total knee replacement. Heterotrophic bone is present posteriorly. The patient received radiation therapy to the primary site and the remaining part of the femur, and was given adjuvant chemotherapy.

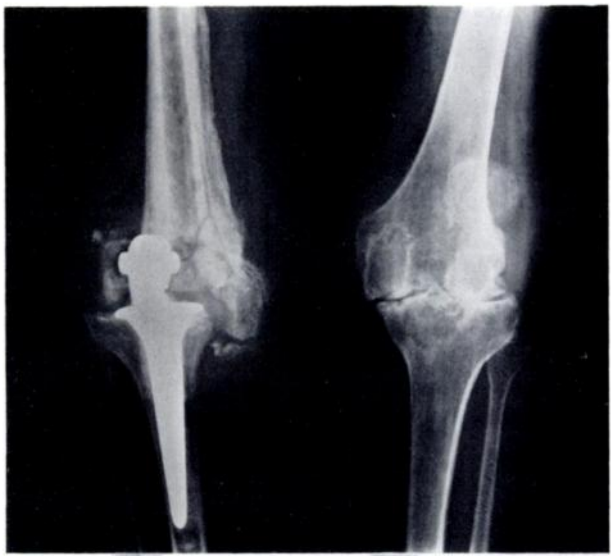

FIG. 3-A

Figs. 3-A, 3-B, and 3-C: Case 13.

Fig. 3-A: Anteroposterior roentgenogram of both knees, showing a broken Buchholz hinged total knee arthroplasty on the right. There is loss of bone structure in the distal end of the femur, and severe gonarthrosis is present in both knees.

knee, total range of knee flexion-extension during gait, stance-phase knee flexion, cadence, percentage of stance phase, time and magnitude of the first peak in the vertical ground-reaction force pattern, and the maximum aft force between the foot and the floor during gait.

The first index, defined as the performance index (Ip), was a measure of the over-all function of the knee joint during gait. This index was calculated for the affected joint, as well as the contralateral joint, by use of the following simple expression:

FIG. 3-B FIG. 3-C

Anteroposterior and lateral roentgenograms made five months after salvage of the failed total knee arthroplasty with a segmental total knee replacement.

$$Ip = \sum_{i=1}^{9} Wi \left(\frac{Pi - Xi}{Pi - ABPi} \right)$$

where Pi = mean value of i^{th} parameter in normals, Xi = i^{th} parameter of a knee joint in a patient, ABPi = worst i^{th} parameter value in all patient populations studied in the laboratory, and Wi = weighting factor for each gait parameter.

Based on equal weighting among the nine gait parameters used, the mean (± standard deviation) performance index for fifty normal subjects (100 knee joints) was 0.04 ± 2.02. Because the normal data have a gaussian distribution, the mean plus two standard deviations can be used as the upper limit for the normal. An increase of the index value reflects the proportionate degree of abnormality of the knee joint. Most of the patients with severe degenerative or rheumatoid disease of the knee had preoperative performance-index scores ranging from 8 to 12. Comparison of this index in the present patient group with that in the normal population allowed us to grade the function of our patient after custom prosthetic replacement. When consecutive scores for each follow-up evaluation of a patient were studied, the functional progress or

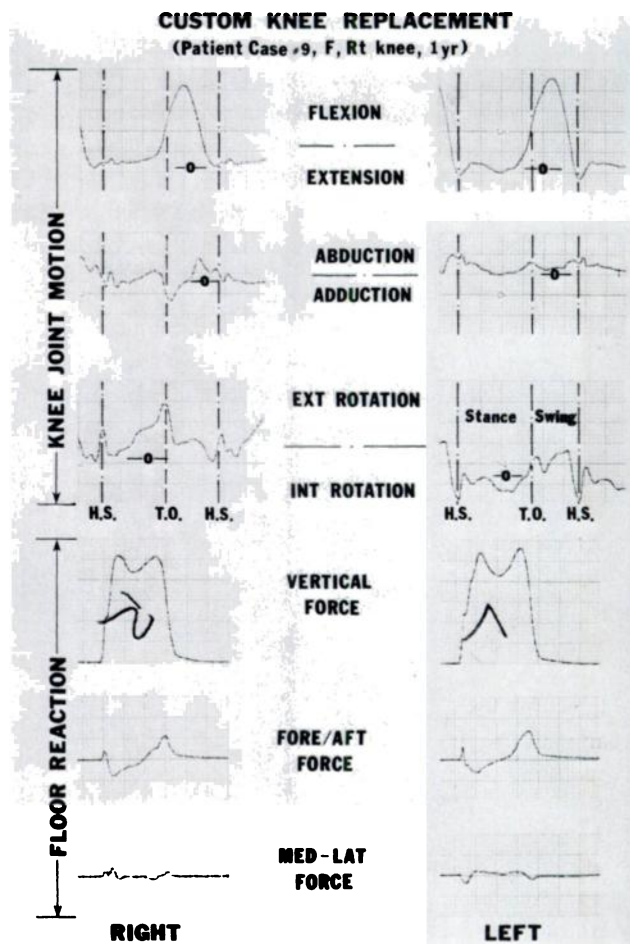

FIG. 4

Motion patterns and foot-floor reaction force during gait of a patient (Case 9) with a custom-made knee replacement. The right knee was replaced with a segmental (distal end of femur) and total knee prosthesis one year before this evaluation. The left knee was normal.

deterioration could be documented to determine what the course of rehabilitation was.

Symmetry of function of the lower extremity in gait reflects the compensatory action of the uninvolved limb to accommodate the loss of function of the involved side. Asymmetrical activity also represents excessive expenditure of body energy. In order to quantitate such added effect to function of the knee joint after prosthetic replacement, a second index, designed as the symmetry index (Is), also was calculated. In this calculation only eight of the nine parameters were used. Cadence was omitted because it applies to both limbs and has no effect on gait symmetry.

The following equation was used in the calculation:

$$Is = \frac{1}{8} \sum_{i=1}^{8} Wi \left(\frac{SPi}{LPi} \right)$$

where SPi = smaller i^{th} parameter between the left and right limbs, LPi = larger i^{th} parameter between the left and right limbs, and Wi = weighting factors.

Based on the same fifty normal subjects studied with equal weighting, the mean symmetry index ($\pm$ standard deviation) was 0.93 ± 0.03. Any score greater than or close to 0.87 was regarded as normal. However, if the symmetry index was substantially less than 0.87, the patient was considered to have an asymmetrical gait, and the degree of asymmetry was inversely proportional to the index value.

If both limbs were equally abnormal, the value for the symmetry index still could reach a significant level to reflect symmetrical but abnormal motion. In general, the symmetry index had to be evaluated in conjunction with the performance index. For convenience, the performance index for the involved side was defined as Ipi and the contralateral side was designated Ipt (Table I).

Nearly all patients evaluated in our laboratory had a performance index within or close to the normal range for the involved side one year after surgery. Their joint function was constantly improving and became stable after two years. The negative performance index value for one patient (Case 10) reflects the young age of this patient and the more energetic and fast gait that is typical in the normal adolescent. The early functional performance of each patient was closely related to the length of immobilization after bone resection. Significant muscle atrophy made rehabilitation difficult. This was evident in one patient (Case 4) particularly, two months after prosthetic replacement. This patient had to wait nearly four months for her prosthesis while the limb was stabilized in a plaster cast. A metal spacer was used to bridge the bone defect during this period. Another patient (Case 8) also showed the gross abnormality for the same reason. Two months after joint replacement, she had to walk with crutches owing to significant loss in strength. However, one year after joint replacement, both of these patients had functional levels of the knee that were close to normal.

The functional scores of the uninvolved side in four patients (Cases 1, 4, 5, and 6) were slightly abnormal during initial evaluation. This was primarily due to the compensatory action of the uninvolved limb used for maintaining body posture and gait symmetry — thus, the symmetry index values for these patients were relatively high. The over-all gait symmetry for the present patient group was satisfactory one year after joint replacement. The worst results were close to 80 per cent of the normal value, which means that no patient had a visible limp. The functional results were not related to the patient's age or diagnosis, or to the length of bone resected.

Discussion

The procedure described is a logical extension of the application of total replacement arthroplasty of the knee. It is best reserved for older patients, with lesions amenable to total resection, who have an excellent chance for cure. The early restoration of function of the knee justifies use of the procedure in younger patients, even after resection of high-grade malignant tumors, when amputation is refused[2]. The technique also may be useful for salvage in non-neoplastic conditions, particularly failed reconstructive procedures in which loss of bone is extensive. In those situations other methods of treatment, including arthrodesis or amputation, also must be considered.

The reconstructive procedure under discussion requires close cooperation between surgeon and engineer in regard to prosthetic design. Each situation must be individualized according to the patient's condition and the extent and location of the lesion, and a custom-made prosthesis is needed for each patient. The size and shape of the segment to be resected are determined from biplanar roentgenograms using an adjacent marking scale. The size and length of the intramedullary canal to be fitted then are measured. A period of six to twelve weeks usually is required to fabricate the prosthesis, and more time is necessary if there is a need to change the prosthesis. The delay may increase the possibility of spread of a malignant tumor and may jeopardize the success of the treatment. Then a two-stage operation may be planned, but prolonged immobilization of the limb in a spica cast causes substantial atrophy of the muscle, which makes rehabilitation difficult. Because of these complications, prostheses with different sizes and segmental lengths have been prefabricated so that they will be available for immediate application. This wide selection of ready-made prostheses is necessary because there is so much variation in the dimensions of the joint and in the extent of the lesion.

The diameter and length of the prosthetic stem are most important in designing a custom-made prosthesis if fracture or loosening is to be avoided. Because all ligament constraint at the knee joint is removed, a hinged prosthesis has to be used as the basic design model.

The fixation to bone of the long component of the prosthesis remains the most critical problem. In all twenty-five patients in this series, methylmethacrylate was used to obtain fixation of the hinged prosthesis. In several patients, callus formed at the interface of the prosthesis and the bone, which may have enhanced the strength of the system under torsional and bending loads. The use of prosthetic devices made of sintered fiber-metal or ceramic, which allow ingrowth of bone for fixation, is currently being investigated.

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Joint Replacement in Non-Ambulatory Patients

BY RUBEN P. ARAFILES, M.D.*, AND RAMON B. GUSTILO, M.D.†, MINNEAPOLIS, MINNESOTA

From the Departments of Orthopaedic Surgery, Metropolitan Medical Center and Hennepin County Medical Center, Minneapolis

ABSTRACT: **We treated eighteen non-ambulatory patients by multiple operations consisting of total replacement of the hip or the knee, or both. Thirteen patients had rheumatoid arthritis, four had degenerative arthritis, and one had had bilateral resection of the femoral head and neck. The patients were followed for an average of forty months. We devised a classification based on the number of joints involved and a rating scale for function. Good to excellent results were achieved in the patients who had two or three joints operated on (with one exception). Fifteen patients became ambulatory and seven could climb stairs. Seven patients were pain-free. The factors responsible for poor results were significant neural problems and loss of motivation. The presence of severe upper-extremity involvement was not an obstacle preventing walking.**

The possibility that a patient who is non-ambulatory because of serious impairment of the hips or the knees (or both) will become ambulatory if the affected joints are subjected to total prosthetic replacement arthroplasty has not been widely explored. In two reports [1,2] eight such patients were described in whom some success was achieved, but delineations of the indications and contraindications for the regimen of operative procedures were not given. Patients fitting the aforementioned description are rather numerous, but often they are regarded as serious surgical risks, either because of their primary medical disease or because of associated systemic lesions, so that the operations are not done. No guidelines for a comprehensive surgical approach therefore have been formulated.

* Metropolitan Medical Center, 900 South 8th Street, Minneapolis, Minnesota 55404.

† Hennepin County Medical Center, 701 Park Avenue South, Minneapolis, Minnesota 55415. Please address reprint requests to Dr. Gustilo.

In this study we present our experience with eighteen patients, and attempt to establish a plan of treatment — that is, to define the indications, contraindications, and complications of multiple joint replacement in non-ambulatory patients.

Clinical Material

We reviewed the records of eighteen non-ambulatory patients treated with multiple total joint arthroplasty between 1970 and 1977. All but two of the patients were followed for an average of forty months (range, fifteen to seventy months). The two most recently treated patients were followed for six months after their last hospitalization. Preoperatively, none of the eighteen patients could get up from a sitting position independently or were capable of walking, even with two helping persons. They were strictly confined to a bed and a wheelchair, and could not even transfer from bed to chair without major assistance from attending personnel. The group consisted of seventeen female patients and one man (Case 7). They had a total of forty-five major joints that had replacement arthroplasty. The period of non-ambulation ranged from five months to fifteen years (average, fifty-eight months), and the duration of the primary joint disease ranged from five to thirty years (average, 14.8 years). Thirteen patients had rheumatoid arthritis, four (Cases 5 through 8) had degenerative arthritis, and one (Case 15) had had bilateral resection of the femoral head and neck. That patient had a chronic malabsorption syndrome with secondary hyperparathyroidism and generalized osteoporosis, and sustained bilateral fracture of the femoral neck. The fractures were treated with nailing and subsequently avascular necrosis and non-union developed. She had three subsequent operations. The bone was so osteoporotic that it would not support a prosthesis. Therefore, resection of the head and neck was done.